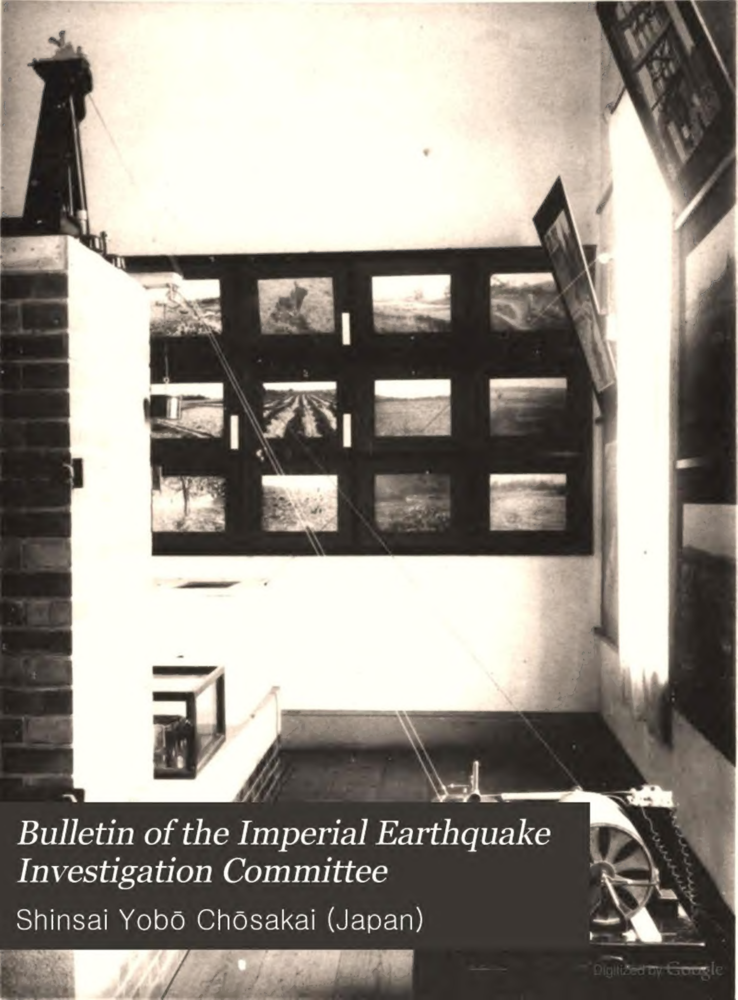

Bulletin of the Imperial Earthquake Investigation Committee

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BULLETIN

OF THE

IMPERIAL EARTHQUAKE INVESTIGATION COMMITTEE.

Vol. I.

1907. TOKYO.

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OF THE

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Vol. I. No. 1.

JANUARY 1907.

TOKYO, JAPAN.

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PREFACE.

The object in issuing the *Bulletin* is to secure a quick publication of short notes and preliminary reports on seismological subjects, more especially such contributions as may be of use in connection with the works of the International Seismological Association. The *Publications*, which contain more lengthy papers, will be issued from time to time, as heretofore.

Jan. 1907.

B. Mano, *President*.
F. Omori, *General Secretary*.
Imperial Earthquake Investigation Committee,
Tokyo, Japan.

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On the Estimation of the Time of Occurrence at the Origin of a Distant Earthquake from the Duration of the 1st Preliminary Tremor observed at any place.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

The approximate time of occurrence ($=t_0$) at the origin of a distant earthquake can be calculated from the duration of the 1st preliminary tremor ($=y_1$) of the latter observed at any place. Thus, let T denote the time interval taken by the initial vibrations of the earthquake motion in travelling the arcual distance ($=x$), between the origin and the given station; and let v_1 and v_2 denote the velocities of propagation corresponding to the 1st and 2nd preliminary tremors. Then we have:—

$$v_1=\frac{x}{T};\quad v_2=\frac{x}{T+y_1};\quad \frac{v_1}{v_2}=1+\frac{y_1}{T}.$$

Putting proper values for v_1 and v_2, namely, $v_1=13.7$ and $v_2=7.2$ km. per sec.*, we obtain:—

$$T=1.108\,y_1 \text{..........................}(1)$$

The values of v_1 and v_2 used in deducing the above formula are those obtained by "difference method," that is to say, calculated by taking the differences of the epicentral distances of different observing stations, and the differences of the times of arrival at the latter of the earthquake motion. For our present purpose, however, it is perhaps better to take the values of the transit velocities deduced by "direct method", or those obtained by dividing the epicentral distance of a station by the time interval taken by the seismic waves in traversing that distance.‡ The results deduced from the observations of the Indian earthquake of April 4, 1905, at different seismological stations, are as follows* :—

---

* These values are slight modifications of those given in the "Publications," No. 13.

$v_1=10.6$ km. per sec.;
$v_2=5.83$,, ,,

Using these values we obtain :—

$$T=1.222\ y_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Let us provisionally take the mean of the two equations, thus:—

$$t_0=t_1-1.165\ y_1\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

in which t_1 denotes the time of commencement of the earthquake motion at a given observatory.

Equation (3), which is to be regarded as being roughly approximate, gives fairly good results, as shown by the following examples.

(1) *Indian Earthquake of April 4, 1905.*

The time($=t_1$) of occurrence in Tokyo of this earthquake was $0^h\ 59^m\ 13^s$ (G. M. T.); the duration ($=y_1$) of the 1st preliminary tremor being 7m 16s. From (3) we thus find, for the time of earthquake occurrence at the centre itself:—

---

‡ See next Article.

* Deduced from the observations at the different stations, whose epicentral distance varied between 20° and 120.°

$$t_0=0\ \ 59^m\ 13^s-(1.165\times436^s)=0^h\ 50^m\ 45^s\ \text{(G. M. T.)}$$

This agrees very well with the time of occurrence at the origin inferred from the magnetograph observations made at Dehra Dun, namely, $0^h\ 49^m\ 48^s$ (G. M. T.)

(2) *San Francisco Earthquake of April 18, 1906.*

The time (t_1) of occurrence in Tokyo was $5^h\ 24^m\ 35^s$ A.M. (in Western States, or Pacific, Time); the duration ($=y_1$) of the 1st preliminary tremor being $9^m\ 49^s$. For the time of occurrence at the origin itself, we have:—

$$t_0=5^h\ 24^m\ 35^s-(1.165\times9^m\ 49^s)=5^h\ 13^m\ 5^s\ \text{A.M.}$$

This seems to be very close to the real value of t_0, since the time of occurrence of the great earthquake observed at the Students' Observatory, Berkeley, and Lick Observatory, Mount Hamilton, were respectively $5^h\ 12^m\ 39^s$ and $5^h\ 12^m\ 12^s$, these two places being not much distant from the epicentral zone. The time of earthquake occurrence at the centre of disturbance was probably $5^h\ 12^m$.

(3) *Calabrian Earthquake of Sept. 8, 1905.*

The time (t_1) of occurrence in Tokyo of the seismic motion was $1^h\ 56^m\ 09^s$ (G.M.T.); the duration (y_1) of the 1st preliminary tremor being $10^m\ 25^s$. Applying these values to our formula, we obtain:—

$$t_0=1^h\ 56^m\ 09^s-(1.165\times625^s)=1^h\ 44^m\ 00^s\ \text{(G.M.T.)}$$

Now according to the seismographical observations made at the Observatory of Messina, the earthquake shock was felt there first at

$1^h\ 43^m\ 17^s \pm 2^s$ (G.M.T.). Hence the time of occurrence at the origin itself was probably about $1^h\ 43^m\ 00^s$, which is close to the result estimated above.

On the Methods of Calculating the Velocities of Earthquake Propagation.

By

F. Omori, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

In the *Publications of the Earthquake Investigation Committee*, Nos. 5 and 13, I have stated the view that the seismic waves corresponding to the different phases of the earthquake motion are propagated along, or parallel to, the earth's surface.

In the discussion of the transit velocities of the different phases of the earthquake motion, given in subsequent Articles, I have followed the same assumption and used throughout the arcual distance instead of the length of the chord. Further, there are two distinct methods of the velocity calculation, as follows.

(*A*) ***Direct Method***, in which the transit velocity is obtained by dividing the epicentral distance of a station by the difference between the times of occurrence of a particular phase of motion at the latter and the origin of disturbance. Thus, if x' be the epicentral distance of a place, and if t' and t_0 be respectively the times of occurrence at the latter and the epicentre, we have:—

$$\text{Velocity} = \frac{x'}{t' - t_0}.$$

(*B*) ***Difference Method***, in which the velocity is obtained by dividing the difference of the epicentral distances of any two stations by the difference of the times of occurrence of a given phase of motion at these stations. Thus, if x' and t' have the same meaning as before and if x'' and t'' be the corresponding quantities at a second place, we have:—

$$\text{Velocity} = \frac{x' - x''}{t' - t'} = \frac{\delta x}{\delta t}.$$

The "difference method" gives always a higher value of the velocity than the "direct method": the discrepancy, which becomes smaller with the increase of the epicentral distance, being markedly shown up to the distance of about 40°.

In the "difference method," we have no need of ascertaining the time of occurrence at the origin of disturbance; the inaccuracy about the position of the epicentre being also avoided in a great measure, provided those stations which are taken for combination lie on one and the same great circle passing through the epicentre, on one side of which they are all situated.

The velocities corresponding to the commencement of the different phases of the earthquake motion will be denoted in subsequent Articles by the same symbols as in my former papers,* namely, as follows:—

v ....Velocity of the 1st preliminary tremor;
v_2............ ,, 2nd ,, ,, ;
v_3............ ,, 1st phase, Principal Portion;
v_4............ ,, 2nd ,, ,, ;
v_5............ ,, 3rd ,, ,, ;
v_6............ ,, 4th ,, ,, ;
v_7............ ,, 5th ,, ,, :
v_8............ ,, 6th ,, ,, .

---

* The "Publications," Nos. 5 and 13.

Preliminary Note on the Cause of the San Francisco Earthquake of April 18, 1906.

By

F. Omori Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. *Introduction.* The great earthquake of April 18, 1906, which caused an enormous amount of damage in San Francisco, furnished a rare opportunity of studying the different earthquake phenomena, especially the seismic effects on various modern structures. Immediately upon the receipt of the news of the catastrophe, the Imperial Government resolved to dispatch to California Professors T. Nakamura and T. Sano, and myself, for the purpose of making investigations on the great seismic disturbance, each according to his professional point of view. The party departed from Tokyo on May 1st, and arrived at San Francisco on the 18th of the same month, the present writer remaining about 80 days in California.

My special thanks are due to Professor George Davidson, and also to Professors Lawson and Leuschner of the University of California, Dr. Gilbert, of the U. S. Geological Survey, Mr. K. Uyeno, Japanese Consul, and other American and Japanese gentlemen, with whom I came in contact and who gave me most cordial assistance during my stay in California.

2. *Time of Occurrence.* The times of earthquake occurrence observed at the Berkeley University and the Lick Observatory were respectively $5^h\ 12^m\ 39^s$ and $5^h\ 12^m\ 12^s$ A.M. (Western States Time, or that of longitude 120° W.); the time of commencement of the disturbance at the origin itself being probably about $5^h\ 12^m$ A.M.

3. *Area of Destructive Motion.* The area, within which more or less damage was done, was very long, extending over a distance of 550 miles along the Pacific coast, from the vicinity of Salinas on the south to the vicinity of Eureka on the north. The width or the extent from the coast of the strong motion area is probably some 50 miles. The earthquake of April 18th was thus greater, in length, than the large Japan earthquake of 1891, the length of whose area of strong motion was about 400 miles. The intensity of motion in the San Francisco earthquake was, however, less violent than in the other, and the amount of the casualties in San Francisco and the different parts of the strongly shaken zone was small comparatively.

4. *Sea Waves.* When an earthquake of inland origin is large and violent, the waters of ponds, rivers or lakes are more or less disturbed. So similarly a great submarine earthquake is often followed by tidal waves; the time interval between the occurrence of the earthquake shock and the arrival of the destructive sea waves varies from a few minutes to several hours, and depends on the distance of the origin from the shore. Tidal waves which are not to be noticed on high seas are developed most markedly in bays with shallow waters and an open mouth, but are quite insignificant along deep-water straight coasts. Many of the great earthquakes originating off the Pacific coast of Alaska and Central and South America have been accompanied by large tidal waves. But fortunately, this phenomenon which sometimes causes more damage than the earthquake disturbance itself was so far not very destructive along the coast of the United States. The great earthquake of April 18th last produced distinct, but very small disturbances of the bay waters which were clearly recorded on the tide gauge at the Presidio (San Francisco); the amount of the rise and fall of the sea water being only about 6 inches, repeated in about 40 minutes. Now the wave period or periods at a place on a given coast remain constant in all the tidal waves, irrespective of the origin or cause; a destructive tidal wave consisting simply in the increase of the amount of the water motion existing more or less at all times, in consequence of a strong submarine earthquake or eruption, a storm, or some other agency. A seismic tidal wave is caused by the movements communicated from the sea bottom to the superincumbent water mass: a very big water disturbance taking place when the earthquake focus is at the sea bottom itself or at a very small depth below it, accompanied by some changes in the contour of the sea bottom. The absence of any great tidal disturbance on April 18th shows that there was no great submarine depression or vertical dislocation, although it seems probable that the northern half of the epifocal zone was under the Pacific.

5. *Sea Shock.* The steamer "Argo" felt the earthquake shock on sea near Cape Mendocino, the sensation being like that caused by running aground. There were other vessels which experienced the earthquake in a similar manner.

Effects like these, which may be called "sea-shocks," are due to the direct transmission through water of vibratory earthquake movements, and not due to the phenomena of the tidal waves which are developed only along coasts where there is some indentation.

6. *Approximate Position of the Centre of Epifocal Zone.* A *rough* idea as to the position of the most central or principal point in the zone, which forms the origin of the earthquake, may be obtained from a good seismograph record taken at the Lick

Observatory, where the preliminary tremor lasted about 10 or 12 seconds, from which it may be calculated that the distance between the point in question and Mt. Hamilton was about 80 or 90 miles; the predominating direction of motion there being NNW and SSE. These data indicate a place near the Tomales Bay as the most central point of the disturbance. The approximate position of the latter may be assumed to be at a point, *latitude* 38°15′N, *longitude* 123°W.

7. The Epifocal Zone. One of the peculiar features in the topography of the State of California is a straight depression whose direction is NNW and SSE and which extends through the valley of the Gualala River, and Tomales and Bolinas Bays, continued further south-eastwards for some distance. This depression, which must have been formed in bygone ages by a great sudden convulsion of the earth's crust, or by the gradual mountain-making force going along the Pacific Coast, shows signs of dislocations caused at no very remote epoch by some great earthquakes, and it is of a special interest that the earthquake of April 18th again produced along the same old weak zone a continuous series of remarkable surface manifestations of cracks, depression, or horizontal slipping, constituting what is called a "fault" in geology. This fault which has been most carefully studied by Dr. Gilbert of the U. S. Geological Survey, Professors Lawson and Branner, and other able geologists of the Berkeley and Stanford Universities, begins on the north at the right-hand mouth of the Alder Creek, near Pt. Arena, and, passes into the ocean at the vicinity of Fort Ross; it again appears at the Bodega Head and at the eastern side of the mouth of Tomales Bay, crosses to Inverness on the west shore of the same bay, and then passes through the vicinity of Pt. Reyes Station, continued to a

PL. I.

Fig. 1. San Francisco and the Vicinity.

Showing the Course of the Great Fault, from Pt. Arena to Chittenden.

Fig. 2 San Francisco and the Vicinity, showing the General Course of the Great Fault.

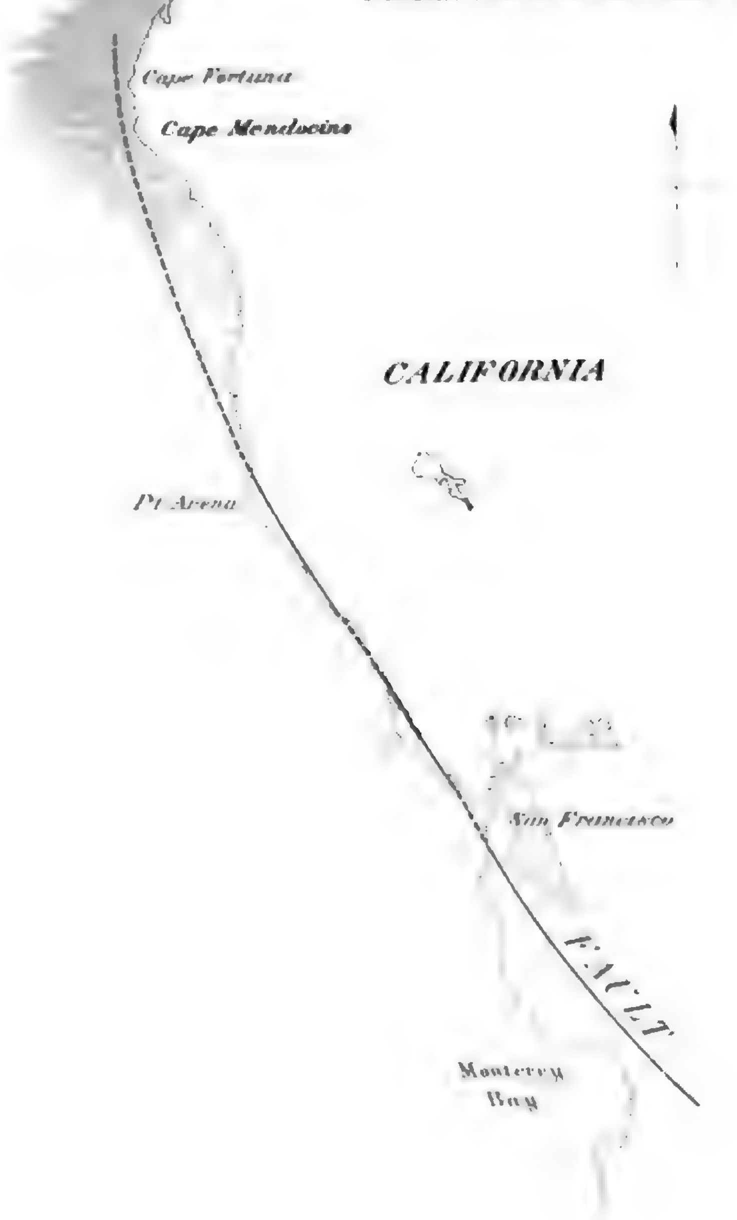
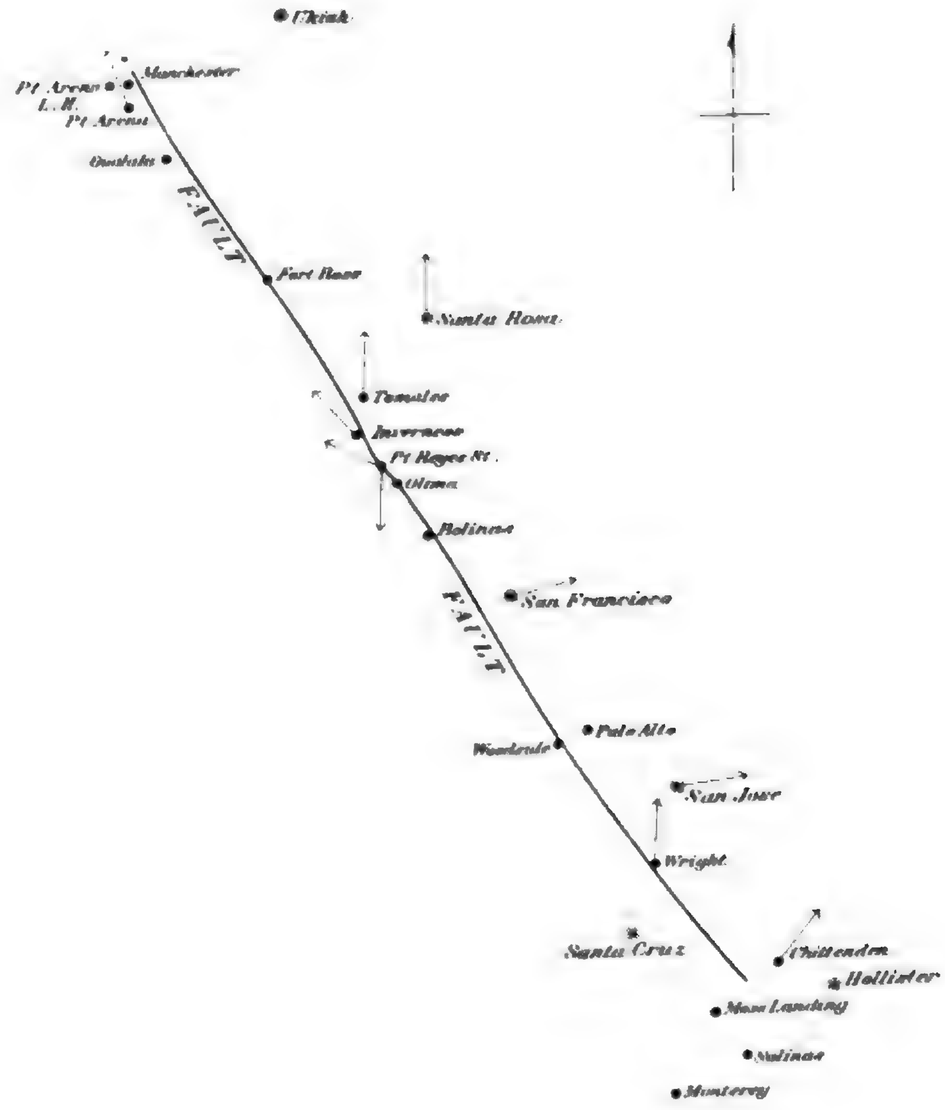

Cape Fortuna
Cape Mendocino
CALIFORNIA
Pt Arena
San Francisco
FAULT
Monterey Bay

Fig. 3. Directions of Motion at Different places on or near the Great Fault.


Ukiah
Manchester
Pt Arena L. H.
Pt Arena
Gualala
FAULT
Fort Ross
Santa Rosa
Tomales
Inverness
Pt Reyes St.
Olema
Bolinas
San Francisco
FAULT
Palo Alto
Woodside
San Jose
Wright
Santa Cruz
Chittenden
Hollister
Moss Landing
Salinas
Monterey

place about 4 miles to the west of the Stanford University; marked disturbances of the ground being also distinctly shown to the south-east, in the vicinity of Wright and Chittenden. The length of the visible fault is thus over 150 miles, being three times that of the fault line in the great Japan earthquake of 1891. It is, further, extremely probable that the north-western part of the present fault is continued beyond Pt. Arena under the Ocean some 120 miles more and extends to the vicinity of Cape Fortuna. That the fault was not a mere surface phenomenon is shown by the appearance of the same disturbance across the tunnel near Wright Station, at a depth of some 700 feet below the mountain surface. See fig. 1 (Pl. I) and fig. 2 (Pl. II).

8. *Shear of the Ground.* The shearing movement of the ground produced many remarkable results; roads, fences, and every other thing crossed by the line of disturbance being cut apart and displaced considerably. There were cases, in which even large redwood trees were split by the shearing motion of the ground. Figure 4 relates to the shear effect observed near Olima, a village situated between the Tomales and Bolinas Bays. The fault passed just in front of a house

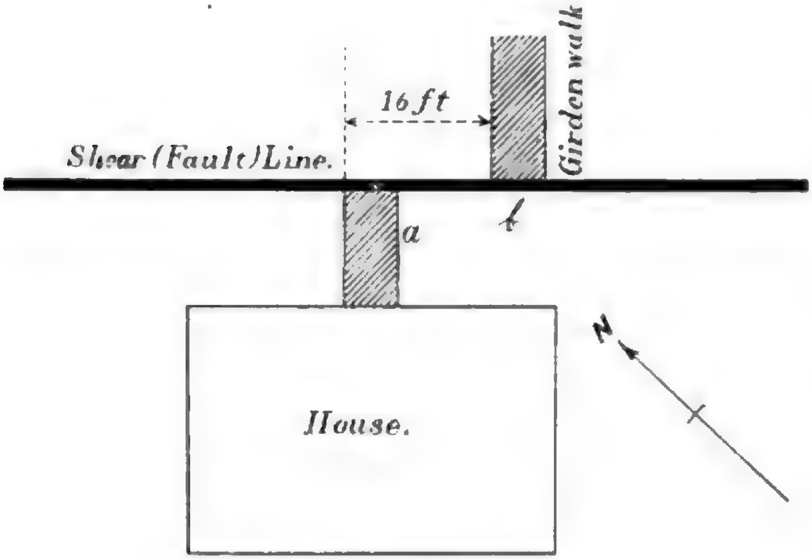


Fig. 4.

(Skinner's Ranch) and produced a relative displacement of 16 feet, a girden walk being carried through that distance from a to b.

Fig. 11 (Pl. III) shows the shearing effects on a pier at Inverness, on the west coast of the Tomales Bay. The end part of the pier was separated from the rest and was displaced about 20 feet towards NNW. The direction of displacement in this particular instance was opposite to the general direction of the relative slip along the great fault line.

Fig. 12 (Pl. III) shows one of the fault cracks produced among the hills above Fort Ross. It will be observed that the new disturbances appeared along a depression marked by a series of small ponds (shown at the right-hand side of the picture), these latter being traces left by a former great earthquake.

Fig. 13 shows the remarkable compression and shear effects along one of the parallel fault cracks, observed on elevated grounds near the town of Manchester, not far from Pt. Arena. A foot-scale placed in the foreground will show the size of the overlapping earth pieces, whose plan is given in fig 8.

9. *Remarks on Shearing Movements.* For the sake of illustration, let us first consider cracks of a wall when the earthquake motion is parallel to the latter.

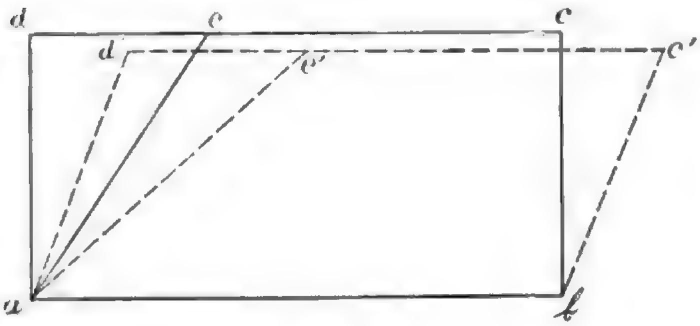


Fig. 5

Let $a\,b\,c\,d$ (fig. 5) be a wall whose bottom side $a\,b$ is fixed, either absolutely or relatively, while the upper side $c\,d$ is brought to the position $c'd'$ as the result of a shearing stress in the direction of a to b. Then the rate of the length change of the line ac, connecting a with any point c on the side cd, will be greatest when the angle dac is equal to 45°. Consequently there will be formed a series of cracks at right angles to the lines of greatest elongation and at an angle of 45° to the base $a\,b$.

Thus, in the case of a strong horizontal motion parallel to the plane of the wall, there will be two sets of cracks at right angles to one another, as in Fig. 6.

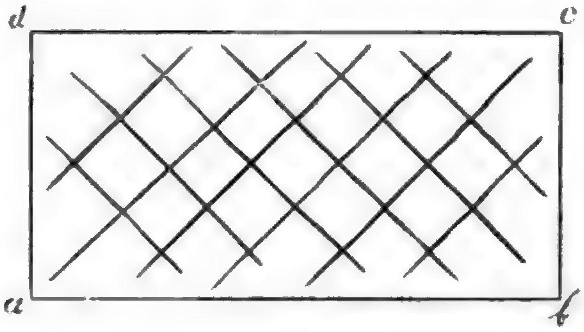


Fig. 6.

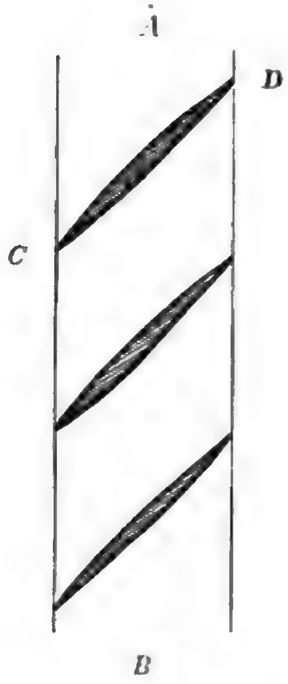


Fig. 7.

AB......Fault Zone.
CD......Shear Cracks.

Fig. 14 (Pl. IV) illustrates some of the cracks of plastered walls observed in St. James Hotel, San Jose.

Secondary Cracks of the Ground. Along the fault line the ground was, as in other cases, very often bulged up, forming a narrow zone of 1 or 2 feet elevation and some 5 or 10 feet width as if raised up by a gigantic mole creeping underground. This sort of ridge, whose formation was due to the shearing action, combined with a compression along the line of dislocation, showed usually a series of secondary oblique cracks, as is diagramatically indicated in Fig. 7. These ground cracks were perfectly similar to the shear cracks of walls considered above.

Figs. 8, 9 and 10, show parts of

the fault lines found near the town of Manchester, not far from Pt. Arena; the dotted lines in each figure indicating the directions of the secondary shear cracks. Fig. 8 is the plan of the remarkable disturbances shown in Fig. 13. In Figs. 9 and 10, the angle between the main fault line and the shear cracks varied between 44° and 47°. In Fig. 8 however, there was evidently a very strong compression, and the shear angle was smaller, namely, 42°.

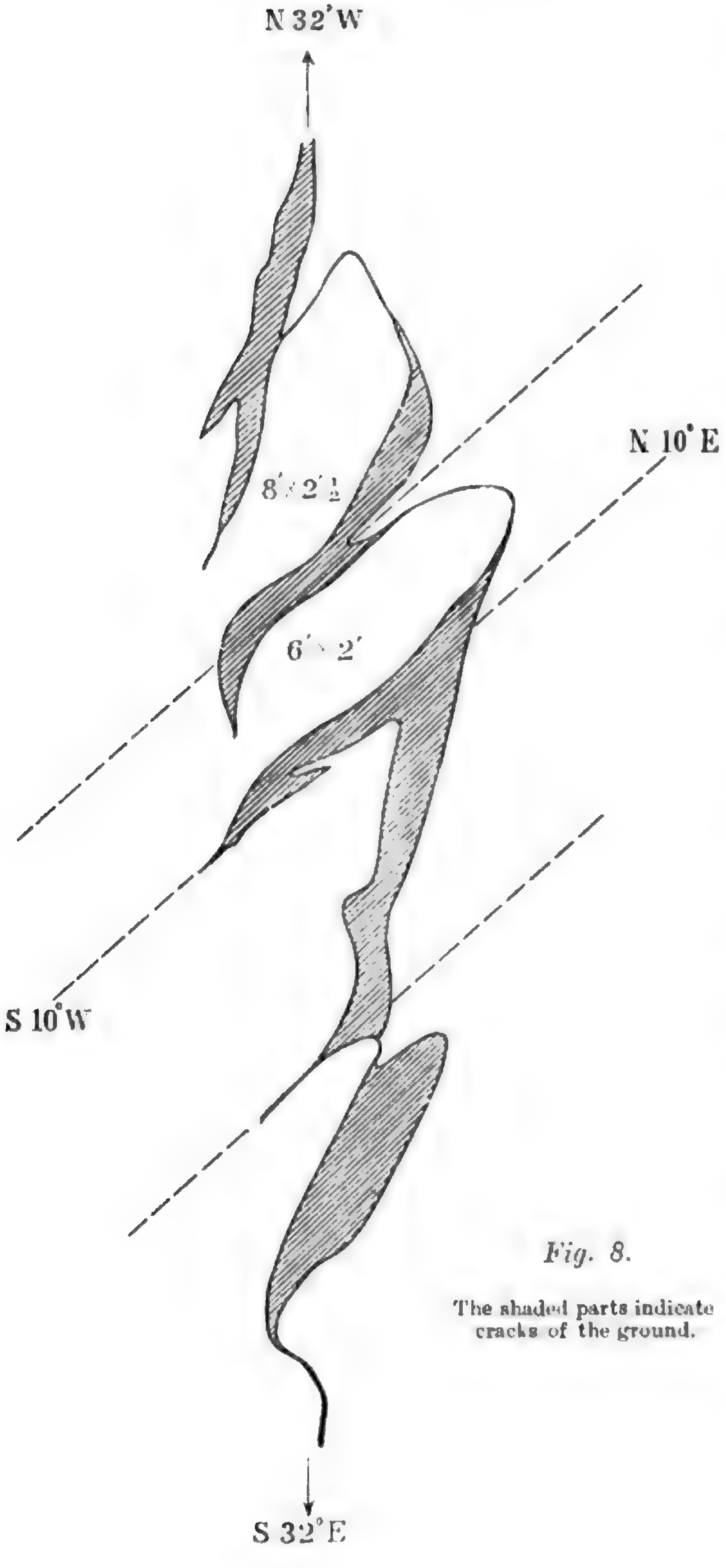


Fig. 8.

The shaded parts indicate cracks of the ground.

I have measured the shear angle in 11 other cases, where it varied between 35° and 47°; the total average value being 40°.

If the shear be accompanied by a horizontal compression at right angles to the fault line, the angle between the latter and the shear cracks will be smaller than 45°, as suggested by Professor A. Inokuty, of the Engineering College, Tokyo Imperial University. The coexistence of a tension normal to the fault plane will, on the other hand, make the same angle greater than 45°.

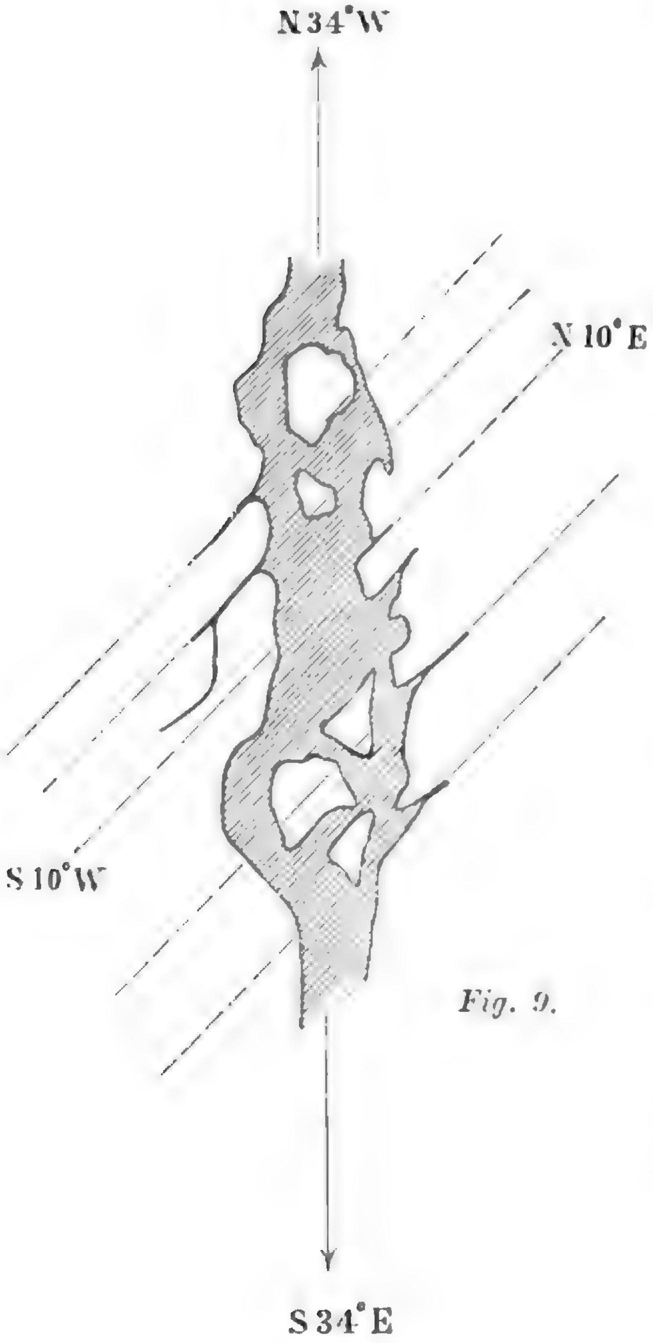


Fig. 9.

10. *Comparison with the Formosa Earthquake of March 17th, 1906.* The local but very severe earthquake in the Kagi Prefecture, Formosa, on March 17, 1906, produced also remarkable surface dislocations, in which the vertical depression and the horizontal shear each amounted to about 8 feet. The angle between the direction of the main fault and that of the shear cracks was on the average 43°.

11. *Landslips, etc.* In the meizoseismal area, there were great many cases of mountain slides. The most remarkable among these was that which occurred near Cape Fortuna (False Cape), where an enormous quantity of debris was detached from a mountain side and was pushed into the Ocean, creating a new promontary of about 3/4 mile length.

At Moss Landing, near Salinas, there were great horizontal disturbances of the sandy ground; the office of the station agent being displaced about 15 feet relative to the adjoining fence.

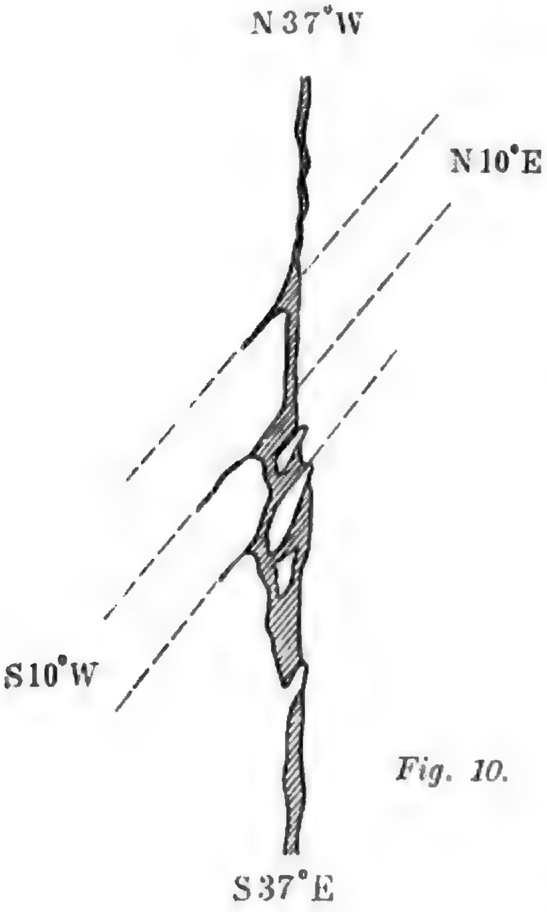


Fig. 10.

12. *Direction of Motion in San Francisco.* Fig. 19 (Pl. VII) shows the directions towards which 520 monuments at the different cemeteries in San Francisco and the vicinity were overturned by the earthquake shock. It will be observed that the greatest number of the monuments were overturned towards the east or east slightly north. The mean direction of overturning is N76°E, which may be regarded as the direction *toward* which the greatest horizontal displacement took place.*

---

* See the "Publications," No. 4.

13. ***Relation to the Great Fault of the Directions of Motion at the neighbouring places.*** The approximate directions of the principal or strongest motion at the different places on or near the fault, each determined from numerous overturned bodies, were as follows:—

A.	San Francisco	N76°E.
	San Jose	N81°E.
	Chittenden	N38°E.
	Watsonville	NE.
	Santa Rosa	N.
	Tomales	N.
	Pt. Reyes Station(East side of Fault)	S.
B.	Pt. Arena	NNW.
	Inverness	NW.
	Pt. Reyes Station (West side of Fault)	WWN.
	Wright	N.

The mean general direction of the fault is N 37° W—S 37° E, this being exactly identical with the direction of the great depression zone before mentioned. The places in Group *A* are situated on the eastern side of the fault line, while those in Group *B* are situated on the western side. It will thus be observed that at the *A* Group places the direction of motion was mostly towards North, North-East, or North-East by East; while at the *B* Group places, the direction was toward North-West, North, or North-West by West. Thus, on the whole, the motion on each side of the fault line had a tendency to diverge, or to be directed away, from the latter. This can be explained on the supposition of a subterranean collapse, or settling down, which would produce an initial inward motion, to be followed by the second and larger outward displacement. Further, the directions of motion at the different places were mostly northward, and not southward. This would mean that the whole meizoseismal zone was first pushed towards SSE, the second or counter motion, which was greater, being consequently directed toward NNW. I presume therefore that the action, which caused the great earthquake of April 18th, was a sudden movement towards South-East by South of the earth's crust at the west coast of California, accompanied by some downward thrust. In this connection it is extremely interesting to note that Mount Tamalpais on the north shore of the Golden Gate has been ascertained, from the trigonometrical measurements, to have moved, between 1851 and 1882, 5.6 feet towards N 12° W, indicating that the earth's crust at this part of America was being strained toward the same direction. The ground on the eastern side of the fault line was generally displaced toward S S E relative to the ground on the other side; the amount of the horizontal slip was maximum at places between Pt. Arena and Pt. Reyes Station and varied from 16 ft. to 20 ft.; the amount of displacement decreasing to about 8 ft. at Woodside, near Stanford University, and to about 4 ft. in the vicinity of Wright. From the uniformity of northward direction of motion it is probable that both sides of the fault line were displaced toward NNW, but the west side was moved more than the east side, the amount of the horizontal slip, or shear, above mentioned being merely relative or differential. In the majority of cases the eastern side was depressed, the maximum amount being 2 ft.

14. From the comparatively very small number of aftershocks, I am inclined to suppose that the main source of the earthquake was situated some considerable depth below the surface. In fact the earthquake seems to have been caused by a

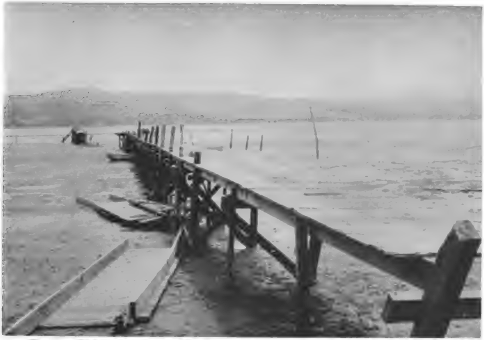


Fig. 11. The shearing effects on a pier at Inverness, on the west coast of the Tomales Bay. The end part of the pier was displaced about 20 feet towards NNW.

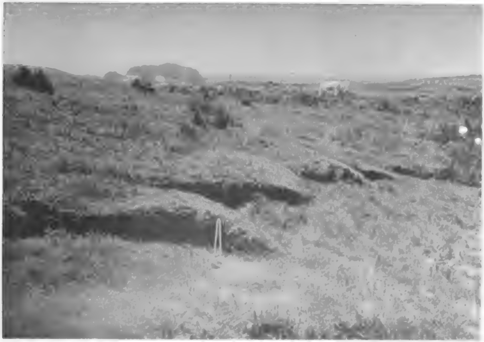


Fig. 13. Remarkable compression and shear effects along one of the fault cracks, produced on elevated grounds near Pt. Arena. A foot-scale placed in the foreground shows the size of the overlapping earth pieces, whose plan is given in fig. 8.

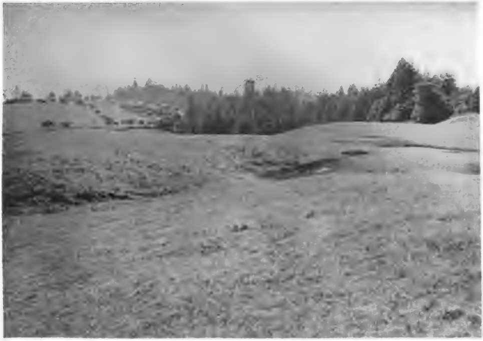


Fig. 12. One of the fault cracks produced among the hills above Fort Ross. The new disturbances appeared along a depression marked by a series of small ponds (shown at the right-hand side of the picture), which are traces left by a former earthquake.

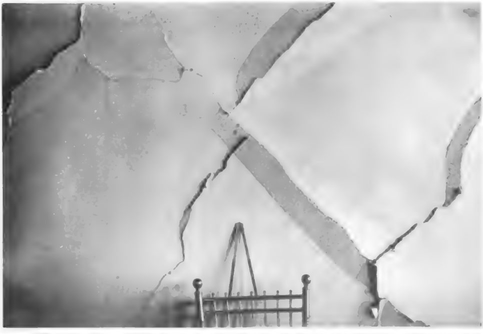


Fig. 14. Some of the cracks of plastered walls, in St. James Hotel, San Jose.

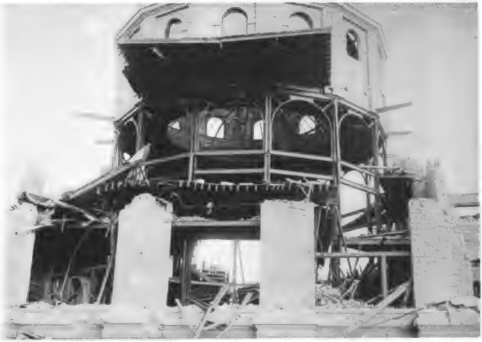


Fig. 15. The damaged condition of the newly erected Library of the Stanford University. The central steel dome behaved as an elastic inverted pendulum.

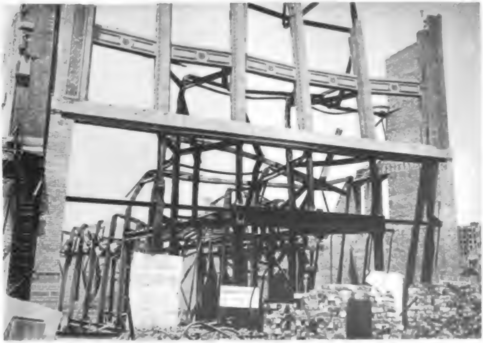


Fig. 16. The ruined condition of a steel-framed brick house in San Francisco, which was dynamited and then burnt, showing the remarkable effects of the intense heat.

The Observatory on the top of the Strawberry Hill, in the Golden Gate Park, San Francisco, built of reinforced concrete.

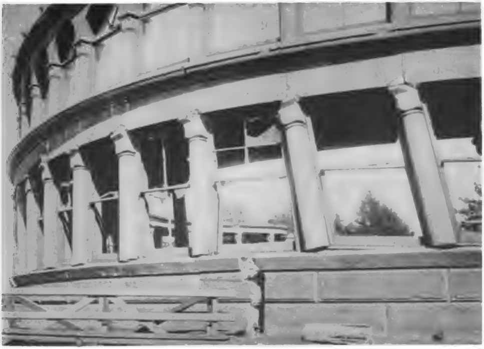


Fig. 17. An outside view of the back part.

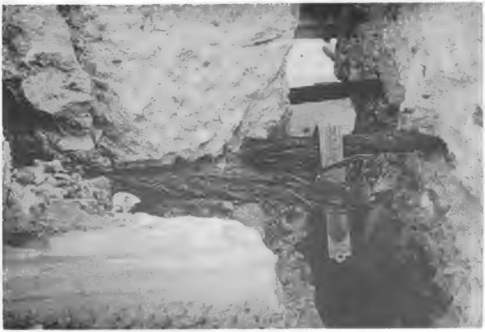


Fig. 18. One of the cracks of the basement wall. The steel cable, one inch in diameter, which was embedded in the concrete, was broken.

disturbance which took place along the old weak line but extended deeper into the earth's crust. The great depth of the main source of disturbance also explains why the intensity of motion was comparatively not very violent, and also why some places such as Santa Rosa, San Jose and Ferndale, not directly on the fault zone, were also badly shaken.

15. *Earthquake Damage.* This earthquake enabled us, for the first time, to study the effects of the shocks on steel-brick and reinforced concrete buildings; there being also numerous other damaged structures, such as ordinary brick, stone and wooden houses, bridges, water-pipes, etc. In San Francisco, the earthquake was followed by fires, which broke out from several places, continued for three days, and entirely destroyed the principal business quarters of the city. The total area of the burnt districts was 4.1 square miles, which is equivalent to 6 times the area of the great London fire of 1666. The amount of casualties was, however, comparatively small, the *ascertained* number of persons killed being about 390. The total number of the killed in the whole earthquake area was probably not more than 1000, the loss of life in Santa Rosa, Stanford University, and other strongly shaken places being slight. In San Francisco, serious damage was confined to the filled-up grounds, where the motion was not so strong as in the cities of Nagoya (max. acceleration=2600 mm. per sec. per sec.), Fukui (max. acceleration =2500 mm. per sec. per sec.), etc., on the occasion of the great Mino-Owari Earthquake of 1891. The double amplitude of motion in San Francisco was probably some 4 inches, and the complete period of vibration about 1 second.

Fig. 15 shows the damaged condition of the newly erected Library of the Stanford University. The central steel dome, which is virtually an elastic inverted pendulum, evidently much vibrated, thereby causing destruction to loosely connected brick and stone parts of the building. The mortar used for cementing the masonry walls was of an exceptionally bad quality.

The damage to the City Hall of San Francisco was also principally due to the same two circumstances, namely, the vibration of its high steel tower, and the bad quality of mortar.

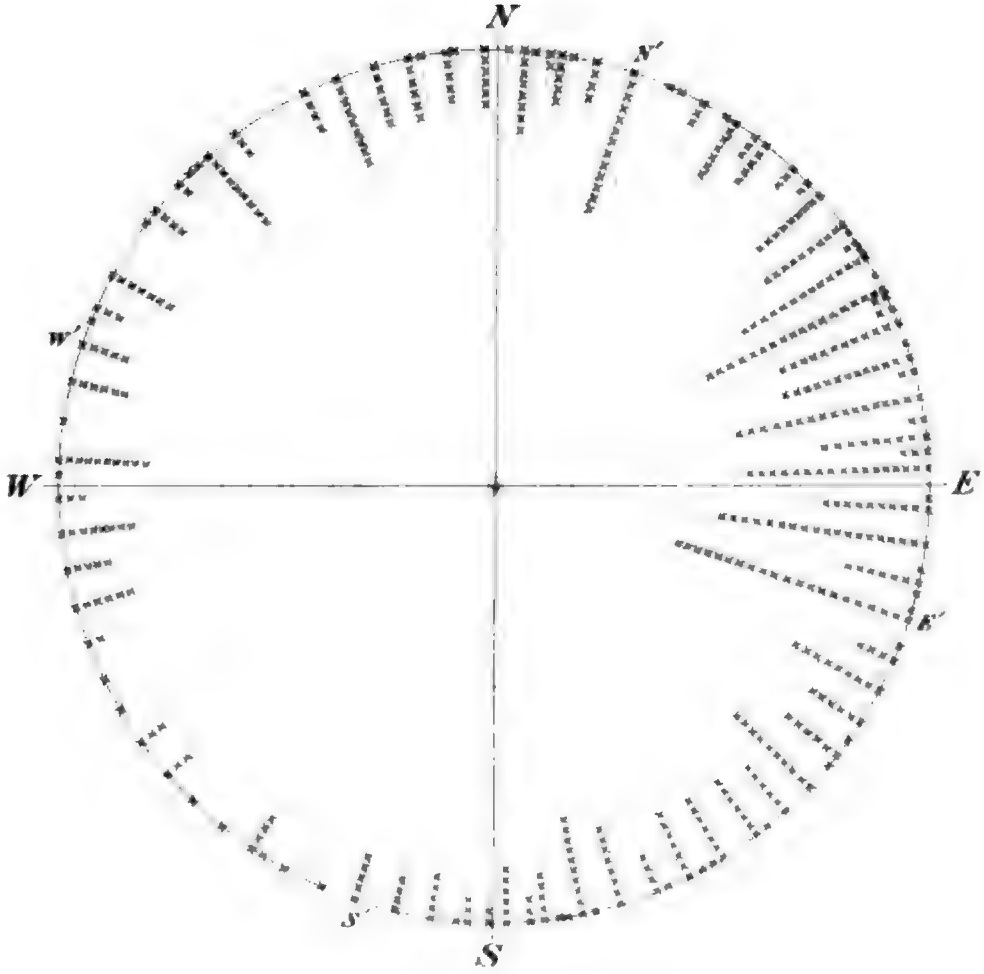
Fig. 16 (Pl. V) shows the ruined condition of a steel-framed brick house in San Francisco, which was dynamited and then burnt. The effects of the intense heat is remarkable, the steel frames being distorted in every possible form as if they had been formed of a soft maleable metal.

Fig. 17 (Pl. VI) gives an outside view of the back part of the Observatory on the top of the Strawberry Hill, in the Golden Gate Park, San Francisco. This building is of reinforced concrete and furnishes a good demonstration of the strength of such structures. The Observatory was indeed seriously damaged and its front portion fell down to the ground, but this was on account of the weakness of the foundation ground which was mostly a filled-up one and was considerably cracked and depressed. Fig. 18 shows, in a larger scale, one of the cracks of the basement wall, similar to that shown in Fig. 17. The steel cable, one inch in diameter, which was embedded in the concrete, was broken. The use of steel cables in concrete walls thus seems to be objectionable, as they are more liable to rusting than solid steel bars. None of the latter used in the cencrete walls and floor of the Observatory, whose section was half inch square, was found broken ; the adhesion of concrete and steel being also very good.

16. ***Recent Seismic Activity.*** Recently there have been a

Fig. 19. Diagram showing the overturning directions of 520 Monuments in San Francisco and the Vicinity.

[Each small cross (×) indicates a monument overthrown in the direction of the radius on which it lies.]



N', E', S', W', indicate the 4 *magnetic* cardinal directions.

number of great earthquakes in different parts of the world, especially along the following two zones :—

(A). The Pacific coast of North and South America.

(B). Himalayas and North Mediterranean zone.

Next two §§ give a short account of the earthquakes belonging to these two zones.

17. *Earthquakes along the West Coast of North and South America.* Within the 7 years preceding the San Francisco earthquake of April 18, 1906, there were, along the Pacific coast of the American continents, seven great earthquakes, on the dates as follows :—

(i) Sept. 4 and 11, 1899 ; and Oct. 9, 1900.
(ii) Jan. 20, 1900 ; and April 19 and Sept. 23, 1902.
(iii) Jan. 31, 1906.

Of the above 7 earthquakes, the three of group (i) took place off the south-west coast of Alaska, two of them being accompanied by great tidal waves. The three earthquakes of the group (ii) strongly shook Mexico and Guatemala (Central America); while the earthquake of group (iii), which was accompanied by tidal disturbances, caused considerable damage in Panama, and the west coast of Columbia and Equador. The approximate positions of these three groups of earthquakes are marked in Fig. 20 by dotted lines, *1*, *2*, and *3*.

As the west coast of the American continents is one of the great seismic zones on the earth, it is to be supposed that the 7 destructive earthquakes above enumerated were not separate or local phenomena, but were the results of great stresses going on along the Pacific coast zone extending from Alaska to South America, manifested at its north and middle parts. Hence an event most naturally to be expected would have been the exten-

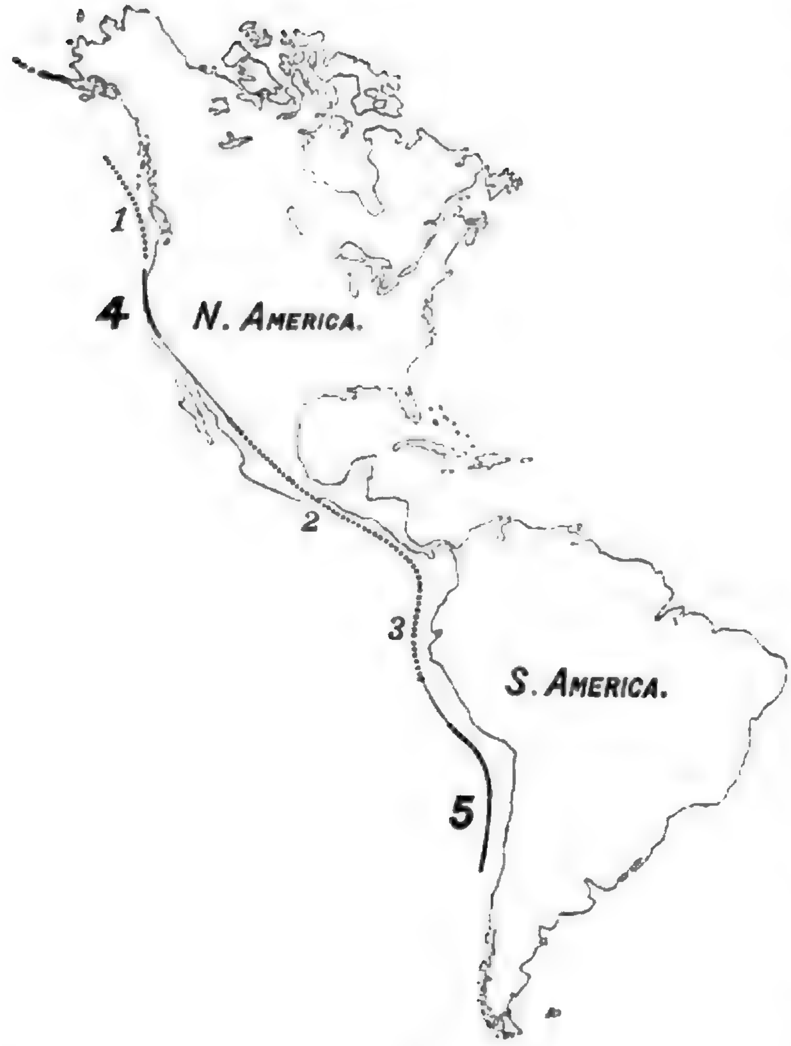


Fig. 20.

sion of the seismic disturbance to the west coast of the United States, which so far had been free from the visitation of disastrous earthquakes. Now this apprehended event has finally taken place on April 8 of this year, the approximate position of the origin being indicated in Fig. 20 by a thick line marked *4*. The great San Francisco earthquake may therefore be regarded as having completed the continuity of the seismic activity along these districts, which latter thus become, for a certain number of years, say 20 or 30 years, seismically a very safe place; *large* earthquakes, which remove a great unstability in the earth's crust, never happening successively at one and the same place.

During my recent stay in San Francisco I explained on several occasions reasonings like the above to newspaper reporters and others, also pointing out that even in the case of a future destructive earthquake, the intensity of motion would not be extremely violent, so that a slight amount of precaution taken in building houses would ensure an almost perfect immunity from earthquake shocks. As to the probable position of the next great shock on the Pacific side of America, I expressed my view that it would be to the south of the equator (that is to say, Chile and Peru),* as it was very likely that the seismic activity would extend to either end along the great zone in question, and as the coast of the countries above named are often visited by strong earth convulsions. I departed on Aug. 4 from San Francisco for home, and arrived on the 22nd of the same month at Yokohama, first there learning of the disastrous shock of Valparaiso, which confirmed my anticipation. The approximate position of the origin of this last earthquake, which took place on Aug. 17 (1906) is indicated in Fig. 20 by a thick line marked 5.

The great stresses going on along the whole Pacific coast of America, which thus resulted in the occurrence of a series of great earthquakes, seems to be connected with the growth of the Rocky and Andes mountain ranges; the Valparaiso earthquake bringing probably the *great* seismic activity along the zone under consideration for the time to an end.

18. *Activity along the Himalayas and North Mediterranean Zone.* With regard to the seismic activity in Asia and Europe, it is to be noted that the unusually severe eruptions of the Vesuvius, which began on about April 7th this year, lasted about one week, and ended on the 13th of the same month. On the following day, namely, April 14 (1906) there took place the destructive earthquake of Kagi District (Formosa), in which 1249 persons were killed. Four days later on there took place the great San

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* This is what I published in the *San Francisco Bulletin* of June 13, 1906.

Francisco earthquake. Whether there existed or not a connection between the Vesuvian eruption and these earthquakes, it is a matter of fact that there was a great seismic activity along the whole length of the zone extending from the north coast of the Mediterranean to the Himalayas, and possibly to Formosa. The different earthquakes belonging to the zone in question, which happened recently, are as follows :—

(i) Assam and Bengal, (India), June 12, 1897.
(ii) Aidin (Smyrna), Sept. 20, 1899.
(iii) Schemacha (Caucasus), Feb. 13, 1902.
(iv) Kashugar (Turkestan), Aug. 22. 1902.
(v) Saloniki (Macedonia), April 4, 1904.
(vi) Kagi (Formosa), April 24, 1904.
(vii) ,, (,,), Nov. 6, 1904.
(viii) Kangra Valley (the Punjab, India), April 4, 1905.
(ix) Calabria (Italy), Sept. 8, 1905.
(x) Kagi (Formosa), March 17, 1906.
(xi) Kagi (,,), April 14, 1906.

Thus great earthquakes took place at the different parts of the zone stretching through Italy, Macedonia, Asia Minor, Caucasus, Turkestan, the outer side of the Himalayas, and Formosa; this proving that the underground stresses were growing along the whole zone. As the seismic disturbances above enumerated occurred in the same epoch as those belonging to the American zone, it is extremely likely that underground stresses reached a maximum all over the earth, resulting in a marked display of seismic disturbances along certain zones of weakness.

19. *Conclusion.* Future studies in various phenomena connected with the movements of the earth's crust might perhaps tend to advance our knowledge respecting the problem of the prediction of great earthquakes, which are often preceded by what may be called "fore-shocks." In the meanwhile, and always, it will be necessary to build houses and other structures strong enough to resist earthquake shocks, a problem which presents no great difficulties.

Tokyo, Nov. 1, 1906.

Preliminary Note on the Seismographic Observations of the San Francisco Earthquake of April 18, 1906.*

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. In response to my circular asking for a copy of the seismographic or magnetographic records of the San Francisco earthquake of April 18, 1906, photographic or printed reproductions of the diagrams have been sent in from the following 35 stations :—*Lick Observatory* ; *Washington, D.C.* ; *Cheltenham* ; *Tacubaya* (Mexico); *Victoria, B.C.*; *Toronto* ; *Honolulu* ; *Mizusawa* ; *Osaka* ; *Kobe* ; *Tadotsu* ; *Taihoku* (Formosa); *Paisley*; *Edinburgh* ; *Kew* ; *Shide* (Isle of Wight); *Strassburg* ; *Pola* ; *Quarto Castello, Querce and Ximeniano* (Florence); *Casamicciola and Porto d'Ischia*, in the Island of Ischia; *San Fernando*; *Tashkent* ; *Cairo* ; *Kodaikanal* (Madras) ; *Calcutta* ; *Dehra Dun*; *Batavia*; *Manila* ; *Zikawei* (Shanghai); *Wellington* and *Christchurch* (New Zealand); *Rio de Janeiro*. I take this opportunity of expressing my thanks to the seismologists in charge of these observatories for having so kindly supplied me with the results of their observations.

Table 1 gives a list of the latitude, longitude, epicentral distance, and the time of occurrence of the 1st preliminary tremor for Tokyo, and for each of the 35 above-mentioned stations, as well as 31 other places, namely :—*Berkeley*; *Ukiah* (California); *Baltimore*; *Baldwin* (Kansas); *Ottawa* ; *Vieques* (Porto *Rico*); *Sitka* (Alaska); *Bergen* (Norway); *Hamburg*; *Göttingen*; *Heidelberg*; *Jena*;

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* A note on the Tokyo observation of the San Francisco earthquake, with one of the seismograms, has been given in the *Publications of the Earthq. Inv. Comm.*, No. 21, App. II.

Krakau; Kremsmuenster; Vienna; Laibach; Budapest; O'Gyalla; Triest; Fiume; Zagreb (Croatia); *Sarajevo* (Bosnia); *Agram; Tortosa; Ebro; Cartuja* (Granada); *Belgrad; Sofia; Jurjew; Tiflis; Fremantle* (Australia). The times of commencement of the 1st and 2nd preliminary tremors relating to these latter places have been taken from Dr. Bauer's paper, entitled "Seismograph and magnetograph records of the San Francisco earthquake,"* and from the monthly or weekly reports of the different seismological observatories.

The velocities of propagation corresponding to the commencements of the 1st and 2nd preliminary tremors are denoted by v_1 and v_2; the calculation being made both according to the "direct method" and the "difference method", as explained in one of the preceding Articles. t_1 and t_2 denote respectively the times of commencement of the 1st and 2nd preliminary tremors at a given station, whose epicentral distance is x. t_0 denotes the time of earthquake occurrence at the origin.

In the calculation of the epicentral distance of a station, the position of the seismic origin has been fixed according to the preceding Article, at a point, *latitude* 38° 15′ N, *longitude* 123° W; the time of commencement of the earthquake motion at the origin being assumed to be $13^h\ 12^m\ 00^s$ G.M.T.

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* The *Popular Science Monthly*, August, 1906.

TABLE I.--OBSERVATION OF THE SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906.

(*......Time determined from magnetograms.)

Place.	Position.		Epicentral Distance. $=x$	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		
Origin	38° 15′ — N	123° — W	———	**$13^h12^m00^s$**
United States.				
University, Berkeley	37° 52′ 24″ N	122°15′11″ W	0° 42′	13 12 39
Lick Observatory......	37° 20′ 25″ N	121°38′44″ W	1 24	13 12 12
Ukiah.	39° 08′ 12″ N	123°13′— W	0 54	13 12 17
Washington, D.C......	38° 54′ 18″ N	77°03′06″ W	35 32	13 19 20
Cheltenham	38° 44′ — N	76°50′30″ W	35 44	13 19 24 13 30 00*
Baltimore	39° 17′ 48″ N	76°37′12″ W	35 46	13 19 24
Baldwin..	38° 47′ — N	95°10′— W	21 42	13 24 —*
Mexico.				
Tacubaya	19° 24′ 18″ N	99°11′37″ W	27° 57′	13 17 58
Canada.				
Victoria, B.C.	48° 27′ — N	123°22′— W	10° 12′	13 14 12
Toronto...................	43° 39′ 36″ N	79°23′24″ W	32 59	13 19 18
Ottawa	45° 25′ — N	75°40′— W	35 27	13 17 59
Porto Rico.				
Vieques	18° 09′ — N	65°26′— W	53° 38′	13 22 17
Alaska.				
Sitka	57° 03′ — N	135°20′— W	20° 29′	13 17 01 13 22 54*
Hawaii.				
Honolulu	21° 19′ — N	153°04′— W	30° 53′	13 19 30 13 27 48*
Japan.				
Mizusawa...............	39° 08′ — N	141°07′— E	70° 50′	13 24 07
Tokyo	35° 42′ 29″ N	139°45′53″ E	73 41′	13 24 35
Osaka	34° 42′ — N	135°31′— E	77 04	13 24 24

TABLE I.—*Continued.*

Place.	Position.		Epicentral Distance $=x$.	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		h m s
Kobe	34° 41′ — N	135°11′— E	77° 17′	13 24 23
Tadotsu..................	34° 17′ — N	133°46′— E	78 27	13 25 07
Taihoku(Formosa) ..	25° 02′ — N	121°30′— E	92 33	13 27 20
Great Britain.				
Paisley	55° 51′ — N	4°25′— W	72° 27′	13 23 12
Edinburgh	55° 57′ 23″ N	3°10′46″ W	72 53	13 23 30
Kew	51° 28′ 06″ N	0°18′46″ W	77 17	13 25 42
Shide (New Port)....	50° 42′ — N	1°19′— W	77 25	13 25 00
Birmingham	52° 28′ — N	1°53′— W	75 54	13 25 03
Norway.				
Bergen	60° 30′ — N	5°25′— E	72° 38′	13 22 46
Germany.				
Hamburg	53° 33′ 55″ N	10°01′19″ E	79° 38′	13 24 32
Göttingen	51° 33′ — N	9°58′— E	81 15′	13 24 34
Heidelberg	49° 23′ 55″ N	5°58′44″ E	81 28	13 25 23
Jena	50° 56′ — N	11°35′— E	82 21	13 24 34
Strassburg	48° 35′ 00″ N	7°46′10″ E	82 49	13 24 56
Austria-Hungary.				
Krakau	50° 03′ 50″ N	19°57′36″ E	85° 51′	13 35 48
Kremsmünster...... ..	48° 03′ — N	14°08′— E	85 40	13 24 25
Vienna	48° 13′ 55″ N	16°20′23″ E	86 17	13 25 42
Laibach................	46° 03′ — N	14°31′— E	87 29	13 25 25
Budapest	47° 22′ 29″ N	19°03′55″ E	87 56	13
O'Gyalla	47° 52′ 24″ N	18°52′32″ E	87 26	13 25 20
Pola	44° 51′ 49″ N	13°50′44″ E	88 15	13 25 56
Triest	45° 38′ 45″ N	13°45′45″ E	87 33	13 24 33
Fiume	45° 19′ 56″ N	14°25′40″ E	88 05	13 40 00
Zagreb	45° 48′ 54″ N	15°58′48″ E	88 13	13 25 25
Sarajevo	43° 52′ — N	18°44′— E	90 53	(?)
Agram	45° 50′ — N	16°08′— E	88 16	13 25 17
Italy.				
Quarto Castello	43° 49′ 11″ N	11°13′11″ E	88 ′05	13 27 15
Querce	43° 47′ 18″ N	11°16′42″ E	88 08	13 25 00
Ximeniano	43° 46′ 46″ N	11°15′24″ E	88 08	13 26 25
Porto d'Ischia	40° 44′ 27″ N	13°56′34″ E	91 46	13 26 59

TABLE I.—*Continued.*

Place.	Position.		Epicentral Distance $=x$.	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		h m s
Casamicciola	40° 44′ 45″ N	13°54′12″ E	91° 44′	13 26 08
Spain.				
San Fernando.	36° 27′ 40″ N	6°12′19″ W	85° 14′	13 25 06
Tortosa	40° 49′ — N	2°34′ — E	86 37	13 24 55
Cartuja (Granada) ...	37° 10′ 4[illegible]″ N	0°05′25″ E	88 08	13 24 40
Ebro	40° 49′ 12″ N	0°29′40″ E	85 36	13 24 55
Servia.				
Belgrad	44° 48′ — N	20°09′ — E	90° 33′	13 36 54
Bulgaria.				
Sofia	42° 42′ — N	23°20′ — E	93° 28′	13 25 00
Russia.				
Jurjew	58° 25′ — N	26°42′ — E	80° 05′	13 24 39
Tiflis	41° 43′ 08″ N	44°47′51″ E	99 16	13 27 17
Taschkent	41° 19′ 31″ N	69°17′42″ E	99 38	13 28 05
Egypt.				
Cairo	30° 04′ 33″ N	31°17′14″ E	107° 35′	13 31
India.				
Kodaikanal	10° 13′ 50″ N	77°27′46″ E	127° 53′	13 31 36
Calcutta	22° 34′ — N	88°24′ — E	112 25	13 19 54
Batavia	6° 08′ — S	106°50′ — E	117 18	13 32 54
Manila	14° 34′ 41″ N	120°58′33″ E	100 14	13 22 42
Shanghai	31° 11′ 33″ N	121°10′45″ E	88 24	13 34 59
New Zealand.				
Wellington	41° 17′ — S	174°47′ — E	97° 40′	13 26 36
Christchurch	43° 31′ 50″ S	172°37′18″ E	100° 23′	13 33 36
Brazil.				
Rio de Janeiro	22° 54′ 24″ S	43°10′21″ W	96° 30′	13 59 41(?)
Australia.				
Fremantle	32° 03′ — S	115°44′ — E	90° 58′	13 46 50

Table II gives the times of occurrence of the 1st preliminary tremor at the different stations, divided into a number of groups, according to the epicentral distance; those places, whose time observations are apparently not quite exact, being *provisionally* excluded.

TABLE II.—SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906.

Different Stations divided into Groups.

Place.	Epicentral Distance $=x$.	Time of occurrence. $=t_1$(G. M. T.)
		h m s
Origin.	——	13 12 00
Victoria, B.C.	10° 12′	13 14 12
Sitka	20° 29′	13 17 01
Tacubaya	27° 57′	13 17 58
Honolulu	30° 53′	13 19 30
Toronto	32° 59′	13 19 18
Mean	**30° 36′**	**13 13 55**
Ottawa	35° 27′	13 17 59
Washington	35° 32′	13 19 20
Cheltenham	35° 44′	13 19 24
Baltimore	35° 46′	13 19 24
Mean	**35° 37′**	**13 19 02**
Vieques	53° 38′	13 22 17
Mizusawa	70° 50′	13 24 07
Tokyo	73° 41′	13 24 35
Osaka	77° 04′	13 24 24
Kobe	77° 17′	13 24 23
Mean	**74° 43′**	**13 24 22**
Bergen	72° 38′	13 22 46

TABLE II.—*Continued.*

Place.	Epicentral Distance =x		Time of occurrence. =t_1 (G. M. T.)		
			h	m	s
Paisley	72°	27′	13	23	12
Edinburgh	72	53	13	23	30
Birmingham	75	54	13	25	03
Kew	77	17	13	25	42
Shide	77	25	13	25	00
Hamburg	79	38	13	24	32
Jurjew	80	05	13	24	39
Göttingen	81	15	13	24	34
Heidelberg	81	28	13	25	23
Jena	82	21	13	24	34
Strassburg	82	49	13	24	56
Mean	**78**	**01**	**13**	**24**	**29**
San Fernando	85°	14′	13	25	06
Ebro	85	36	13	24	55
Kremsmünster	85	40	13	24	25
Vienna	86	17	13	25	42
Tortosa	86	37	13	24	55
O'Gyalla	87	26	13	25	20
Laibach	87	29	13	25	25
Triest	87	33	13	24	33
Quarto Castello	88	05	13	27	15
Querce	88	08	13	25	00
Ximeniano	88	08	13	26	25
Cartuja (Granada)	88	08	13	24	40
Zagreb	88	13	13	25	25
Pola	88	15	13	25	56
Agram	88	16	13	25	17
Ischia*	91	45	13	26	34
Taihoku	92	23	13	27	20
Sofia	93	28	13	25	00
Mean	**88**	**09**	**13**	**25**	**31**
Wellington	97°	40′	13	26	36
Tiflis	99	16	13	27	17
Taschkent	99	38	13	28	05
Batavia	117	18	13	32	54
Kodaikanal	127	53	13	31	36
Mean	**108**	**21**	**13**	**29**	**18**

* Mean of Porto d'Ischia and Casamicciola.

2. *Velocity of Propagation of the 1st Preliminary Tremor.*

"DIRECT METHOD."

(i)* Victoria, B.C.

$x = 10°12' = 1133$ *km.*

$t_1 = 1^h 14^m 12^s$

$t_1 - t_0 = 2^m 12^s = 132$ sec.

$v_1 = 8.58$ *km* per sec.

(ii)* Sitka.

$x = 20° 29' = 2276$ *km.*

$t_1 = 1^h 17^m 01^s$

$t_1 - t_0 = 5^m 01^s = 301$ sec.

$v_1 = 7.56$ *km* per sec.

(iii) Tacubaya, Honolulu, Toronto :—

Mean......$x = 30° 36' = 3400$ *km.*

$t_1 = 1^h 18^m 55^s$

$t_1 - t_0 = 6^m 55^s = 415$ sec.

$v_1 = 8.19$ *km* per sec.

(iv) Eastern Parts of Canada and the United States:—*Ottawa, Washington, D.C., Cheltenham, Baltimore.*

Mean......$x = 35° 37' = 3956$ *km.*

$t_1 = 1^h 19^m 02^s$

$t_1 - t_0 = 7^m 02^s = 422$ sec.

$v_1 = 9.37$ *km* per sec.

(v)* Vieques (Porto Rico).

$x = 53° 38' = 5958$ *km.*

$t_1 = 1^h 22^m 17^s$

$t_1 - t_0 = 10^m 17^s = 617$ sec.

$v_1 = 9.66$ *km* per sec.

(vi) Japan:—*Mizusawa, Tokyo, Osaka, Kobe.*

Mean......$x = 74° 43' = 8301$ *km.*

$t_1 = 1^h 24^m 22^s$

$$t_1-t_0=12^{m}22^{s}=742\text{ sec.}$$
$$v_1=11.19\ km\text{ per sec.}$$

(vii) Norway, Great Britain, Germany, Russia:—*Bergen, Paisley, Edinburgh, Birmingham, Kew, Shide, Hamburg, Göttingen, Heidelberg, Jena, Strassburg, Jurjew.*

$$\textit{Mean}\ldots\ldots x=78^\circ\ 01'=8667\ km.$$
$$t_1=1^{h}24^{m}29^{s}$$
$$t_1-t_0=12^{m}29^{s}=749\text{ sec.}$$
$$v_1=11.57\ km\text{ per sec.}$$

(viii) Spain, Austro-Hungary, Italy, Burgaria, Formosa:—*San Fernando, Tortosa, Kremsmuenster, Vienna, O'Gyalla, Laibach, Triest, Quarto Castello, Querce, Ximeniano, Cartuja, Zagreb, Pola, Agram, Ischia, Taihoku, Sofia.*

$$\textit{Mean}\ldots\ldots x=88^\circ\ 09'=9793\ km.$$
$$t_1=1^{h}25^{m}31^{s}$$
$$t_1-t_0=13^{m}31^{s}=811\text{ sec.}$$
$$v_1=12.08\ km\text{ per sec.}$$

(ix) New Zealand, Turkestan, Java, India:—*Wellington, Christchurch, Tiflis, Taschkent, Batavia, Kodaikanal.*

$$\textit{Mean}\ldots\ldots x=108^\circ\ 21'=12038\ km.$$
$$t_1=1^{h}29^{m}18^{s}$$
$$t_1-t_0=17^{m}18^{s}=1038\text{ sec.}$$
$$v_1=11.60\ km\text{ per sec.}$$

Excluding provisionally the three cases of single observations, (i), (ii), and (v) marked with *asterisks*, the six groups (iii), (iv), (vi)—(ix), may be divided into two sets as follows:—

$$(\mathbf{a})\ldots\ldots(\text{iii}),\ (\text{iv})\ \ldots\ldots\ldots\ldots \begin{cases} x=30^\circ\ 36'; & v_1=8.19\ km\text{ per sec.}\\ x=35^\circ\ 37'; & v_1=9.37\qquad ,, \end{cases}$$

$$\textbf{Mean}\ \ldots\ldots\ldots\ldots x=33^\circ\ 7';\ v_1=\mathbf{8.78}\qquad ,,$$

$$(\mathbf{b})\ldots\ldots(\text{vi}),\ (\text{vii}),\ (\text{viii}),\ (\text{ix}). \begin{cases} x=74^\circ\ 43'; & v_1=11.19\ km\text{ per sec.}\\ \quad 78\ \ 01 & \quad 11.57\\ \quad 88\ \ 09 & \quad 12.08\\ \quad 108\ \ 21 & \quad 12.60 \end{cases}$$

Mean.............. $x = 87° \ 19'$ $\quad v_1 = \mathbf{11.61}$ *km* per sec.

Comparing the latter value with the velocity deduced by "difference method" given below, we obtain:—

$$\frac{v_1\,(\text{difference method})}{v_1\,(\text{direct method})} = \frac{13.97}{11.61} = 12.03$$

This ratio is to be regarded as holding good, so far as the velocity calculated by "direct method" is concerned, for the distance x of about 70° to 100°.

The relation between the x and v_1 calculated by "direct method," for the six groups (iii), (iv), (vi)......(ix), is graphically shown in Fig. 2, Pl. IX.

"DIFFERENCE METHOD."

In calculating the velocity v_1 by the "difference method", I have taken only the mean values relating to the Groups (iii), (iv), (vi)......(ix). The relation between the time of commencement and the epicentral distance is illustrated in Fig. 1, the dotted curve being drawn with free hand through the mean position. Assuming a linear relation between the time of commencement and the epicentral distance for the limits of the latter quantity given by the groups (iii) and (ix), as indicated by the straight line in Fig. 1, and calculating by the method of Least Squares, we obtain

$$v_1 = \mathbf{13.97} \ km. \text{ per sec.}$$

3. *Velocity of Propagation of the 2nd Preliminary Tremor.*

Table III gives, for 21 different stations, the epicentral distance and the time $(=t_2)$ of commencement of the 2nd preliminary tremor; the stations being grouped as follows:—

Group (i). United States and Canada:—*Toronto, Cheltenham, Baltimore.*

Group (ii). Japan :—*Mizusawa*, *Tōkyo*, *Osaka*, *Kobe.*

Group (iii). Central Europe:—*Hamburg*, *Jurjew*, *Göttingen*, *Jena*, *Strassburg*, *San Fernando*, *O'Gyalla*, *Quarto Castello* (Florence), *Zagreb.*

The epicentral distance varied between 79° 38′ and 88° 13′.

Group (iv). *Tiflis*, *Manila*, *Calcutta*, the epicentral distance varying between 99° 16′ and 112° 25′.

Besides these, there are two single stations of Birmingham ($x=75°\ 54'$) and Sofia ($x=93°\ 28'$).

The relation between the time (t_2) and the distance x, for the four groups (i)—(iv), is illustrated in Fig. 3, (Pl. X).

TABLE III.—SAN FRANCISCO EARTHQUAKE.

Time of Commencement of the 2nd Preliminary Tremor.

Place.	Epicentral Distance $=x$.		Time of Commt. of 2nd Prel. Tremor. $=t_2$.		
			h	m	s
Toronto	32°	59′	13	25	00
Cheltenham	35	44	13	25	04
Baltimore	35	46	13	25	12
(i) **Mean**	**34**	**50**	**13**	**25**	**05**
Mizusawa	70°	50′	13	33	14
Tokyo	73	41	13	34	24
Osaka	77	04	13	34	13
Kobe	77	17	13	34	19
(ii) **Mean**	**74**	**43**	**13**	**34**	**03**
Birmingham	75°	54′	13	35	07
Hamburg	79°	38°	13	34	57
Jurjew	80	05	13	34	43
Göttingen	81	15	13	34	42
Jena	82	21	13	35	09

Place.	Epicentral Distance $=x$.		Time of Commt. of 2nd Prel. Tremor $=t_2$.		
			h	m	s
Strassburg	82°	49′	13	35	20
San Fernando	85	14	13	35	18
O'Gyalla	87	26	13	36	08
Quarto Castello	88	05	13	37	58
Zagreb	88	13	13	35	32
(iii) **Mean**	**83**	**54**	**13**	**35**	**32**
Tiflis	99°	16′	13	39	13
Manila	100	14	13	37	02
Calcutta	112	25	13	40	48
(iv) **Mean**	**103**	**58**	**13**	**39**	**01**

Calculating the velocity of propagation from the *mean* values given in the above table we obtain the following results.

"DIRECT METHOD."

(i) $x=34° \ 50'=3870\ km.$

$t_2=1^h25^m05^s$

$t_2-t_0=13^m05^s=785$ sec.

$v_2=4.93\ km.$ per sec.

(ii) $x=74° \ 43'=8301\ km.$

$t_2=1^h34^m03^s$

$t_2-t_0=22^m03^s=1323$ sec.

$v_2=6.27\ km.$ per sec.

(iii) $x=83° \ 54'=9321\ km.$

$t_2=1^h35^m32^s$

$t_2-t_0=23^m32^s=1412$ sec.

$v_2=6.60\ km.$ per sec.

(iv) $x=103° \ 58'=11551\ km.$

$t_2=1^h39^m01^s$

$$t_2-t_0=27^{m}01^{s}=1621 \text{ sec.}$$

$$v_2=7.13 \ km. \text{ per sec.}$$

The above results may be summarized as follows :—

(A) For (i) in which the epicentral distance was 34° 50′, the *direct* velocity v_2 was 4.93 *km.* per sec.

(B) For (ii) and (iii), in which the distance was 74° 43′ to 83° 54′, the mean values are :

$$x=79° \ 19', \quad v_2=6.44 \ km. \text{ per sec.}$$

(C) For (iv), in which the distance was great and equal to 103°58′, the velocity v_2 was 7.13 *km.* per sec.

The relation between the epicentral distance and the velocity v_2, calculated by the "direct method", is graphically shown in Fig. 4, Pl. XI, the curve being, within the limits of 34° 50′ and 103° 58′, approximately straight.

"DIFFERENCE METHOD."

(iv)–(i) ;......$\partial x=69° \ 08'=7680 \ km.$

$$\partial t=13^{m}55^{s}=835 \text{ sec.}$$

$$v_2=9.20 \ km. \text{ per sec.}$$

(iv)–(ii) ;......$\partial x=29° \ 15'=3249 \ km.$

$$\partial t=4^{m}58^{s}=298 \text{ sec.}$$

$$v_2=10.90 \ km. \text{ per sec.}$$

(iv)–(iii) ;......$\partial x=20° \ 04'=2227 \ km.$

$$\partial t=3^{m}29^{s}=209 \text{ sec.}$$

$$v_2=10.66 \ km. \text{ per sec.}$$

(iii)–(i) ; .....$\partial x=49° \ 04'=5450 \ km.$

$$\partial t=10^{m}27^{s}=627 \text{ sec.}$$

$$v_2=8.69 \ km. \text{ per sec.}$$

(iii)−(ii)……$\delta x = 9° 11' = 1010$ *km.*

$\delta t = 1^m 29^s = 89$ sec.

$v_2 = 11.35$ *km.* per sec.

(ii)−(i) ……$\delta x = 39° 53' = 4430$ *km.*

$\delta t = 8^m 58^s = 538$ sec.

$v_2 = 8.24$ *km.* per sec.

The above results may be summarized as follows :—

(A). For the three combinations, in each of which the shorter distance was 34° 50′, the velocity v_2 was small, namely,

$v_2 = 9.20$ *km.* per sec.
8.69
8.24

Mean ……**8.71** *km.* per sec.

(B). For the three remaining combinations, in each of which the shorter distance was over 74° 43′, the velocity was greater :—

$v_2 = 10.90$ *km.* per sec.
10.66
11.35

Mean……**10.97** *km.* per sec.

Mean value of v_2. Taking the four groups (i)……(iv), Table III, and assuming a linear equation between the epicentral distance and the time of commencement of the 2nd preliminary tremor, we obtain by method of Least Squares, the following mean value :—

$v_2 =$ **9.02** *km.* per sec.

Comparing this with the value of the velocity v_1 given in §2, we see that

$$\frac{v_1}{v_2} = \frac{13.97}{9.02} = 1.549\,;$$

this ratio relating to the velocities between the distance limits of about 30° and 100°

4. *Duration of the 1st Preliminary Tremor.*

Table IV gives the duration (y_1) of the 1st preliminary tremor at the different stations, arranged according to the epicentral distance (x).

TABLE IV.—SAN FRANCISCO EARTHQUAKE.

Duration of the 1st Preliminary Tremor.

Place.	Epicentral Distance$=x$	Duration of 1st Prel. Tremor$=y_1$
		m s
Tacubaya	27° 57′	4 53
Ottawa	35° 27′	5 31
Washington	35° 32′	5 26
Cheltenham	35° 44′	5 38
Mean	**35° 34′**	**5 32**
Vieques (Porto Rico)	53° 38′	7 38
Mizusawa	70° 50′	9 07
Tokyo	73° 41′	9 49
Osaka	77° 04′	9 49
Kobe	77° 17′	9 56
Mean	**74° 43′**	**9 40**
Paisley	72° 27′	10 12
Birmingham	75° 54′	10 04
Kew	77° 17′	8 12
Hamburg	75° 54′	10 25
Jurjew	80° 05′	10 04
Göttingen	81° 15′	10 08
Jena	82° 21′	10 35
Strassburg	82° 49′	10 24
Mean	**78° 30′**	**10 01**
Ximeniano	88° 08′	10 57
Querce	88° 08′	10 42
Quarto Castello	88° 05′	10 56

TABLE IV.—*Continued.*

Place.	Epicentral Distance$=x$.	Duration of 1st Prel. Tremor$=y_1$.
Ischia	91° 45′	$11^m\ 27^s$
Mean	**89° 02′**	**11 01**
Tiflis	99° 16′	11 56
Manila	100° 14′	14 20
Mean	**99° 45′**	**13 08**

According to Table IV the mean values of the epicentral distance (x) and the corresponding duration (y_1) of the 1st preliminary tremor are as follows:—

$x=27^\circ\ 57'$	;	$y_1=4^m\ 53^s$
$35^\circ\ 34'$		5 32
$53^\circ\ 38'$		7 38
$74^\circ\ 43'$		9 40
$78^\circ\ 30'$		10 01
$89^\circ\ 02$		11 01
$99^\circ\ 45'$		13 08

The relation of x and y_1, as illustrated in Fig. 5, Pl. XII, is nearly linear. Assuming, therefore, an equation of the 1st degree between these two quantities, and determining the constants by the method of Least Squares, we obtain the following formula:—

$$x = 16.79\, y_1 - 1618\ km.$$

The deduction of this equation, whose application is limited between x=about 30° and 100°, differ from that of similar equations hitherto given in that the data utilized in the calculation relate all to one and the same earthquake, and not to the observations at one given station of different earthquakes.

5. *Milne Horizontal Pendulum Seismograms obtained at San Fernando and Wellington.*

In Figs 6 and 7, Pl. XIII, I reproduce the Milne Horizontal Pendulum seismograms obtained at San Fernando (Spain) and Wellington (New Zealand); these records having been selected on account of the clearness with which they indicate the W_2 waves, or the earthquake vibrations propagated along the major arcs of the earth. The explanation to the Wellington diagram is that given by Mr. G. Hogben.

In each diagram, the letter *A* marks the probable commencement of the 3rd phase of the principal portion.

The portion marked W_3 in the San Fernando diagram may correspond to the repetition of the earthquake motion propagated first along the minor arc, which came back after making one complete circuit of the earth.*

The epicentral distances of San Fernando and Wellington are respectively 85° 14′ and 97° 40′, the former station being 12° 26′ or 1381 km nearer to the origin of the earthquake. Accordingly the W_2 motion occurred some minutes earlier in the Wellington record than in the San Fernando one.

San Fernando Seismogram. Commencement of the earthquake $=13^h\,25^m\,06^s$. The principal portion began approximately at $13^h\,49^m\,30^s$. The first maximum motion, probably corresponding to the 3rd phase of the principal portion, occurred at $13^h\,57^m\,18^s$; the 2nd maximum occurring at $14^h\,03^m\,05^s$.

The W_2 motion began at $15^h\,13^m$, the 3rd phase of its principal portion commencing at $15^h\,32^m\,42^s$. The motion remained active till $15^h\,46^m$.

Wellington Seismogram. Commencement of the earthquake

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* Mr. Hogben identifies the earthquake movements for the successive repetitions.

PL. VIII.

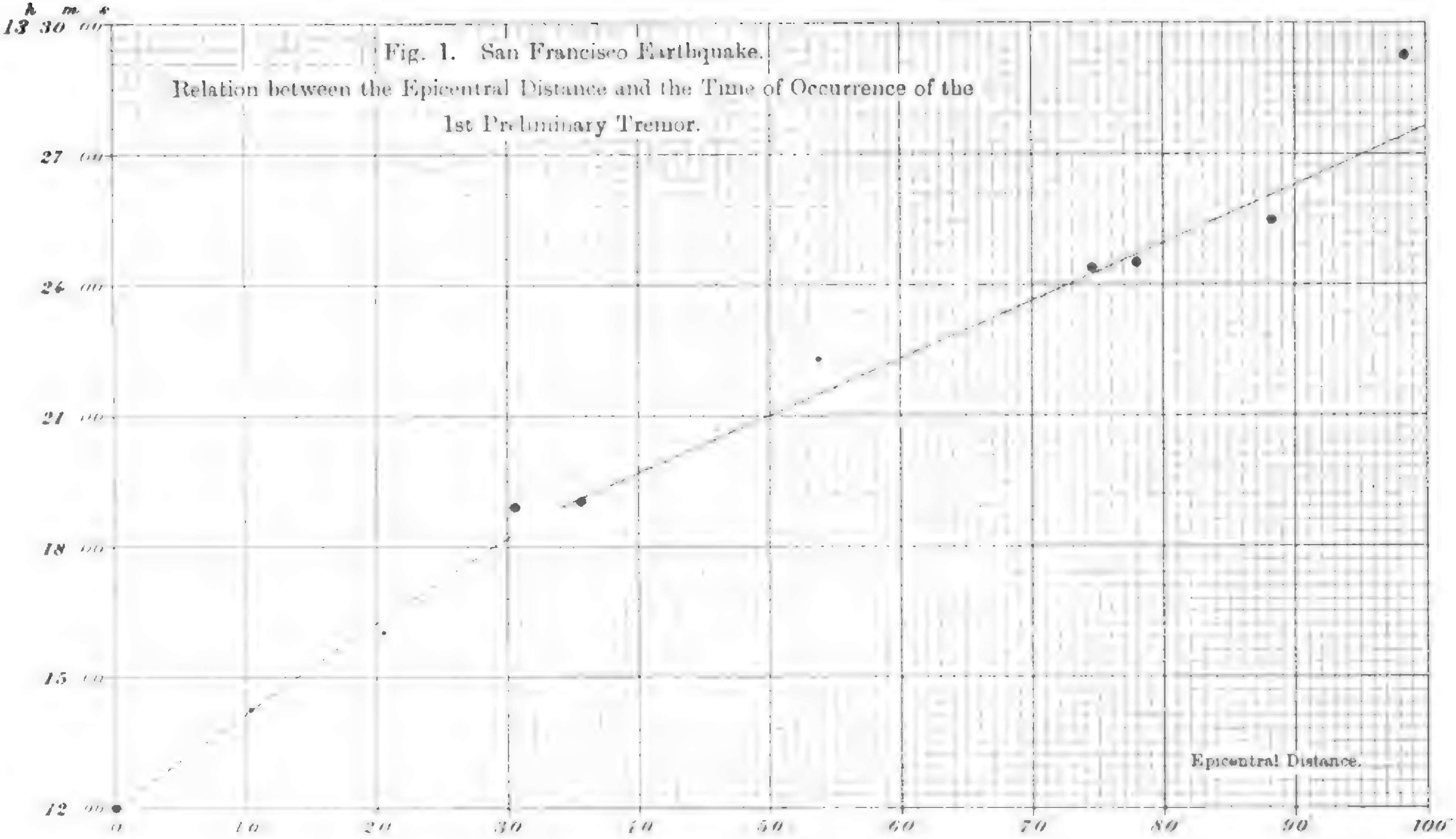


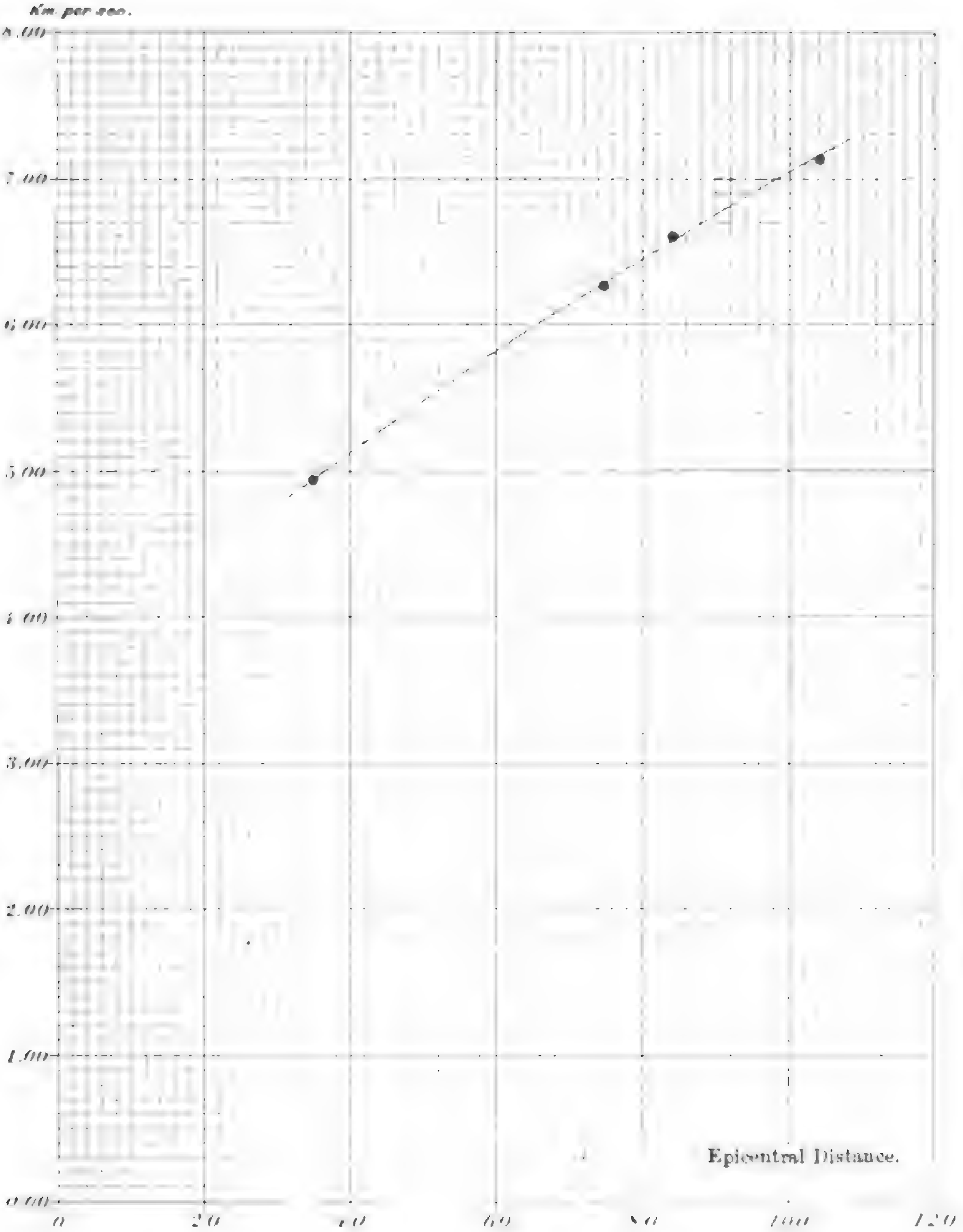
Fig. 1. San Francisco Earthquake.

Relation between the Epicentral Distance and the Time of Occurrence of the 1st Preliminary Tremor.

A large dot relates to a mean group value, while a small dot relates to a single value.

Fig. 4. San Francisco Earthquake.

Relation between the Epicentral Distance and the Velocity v_1, "directly" calculated.



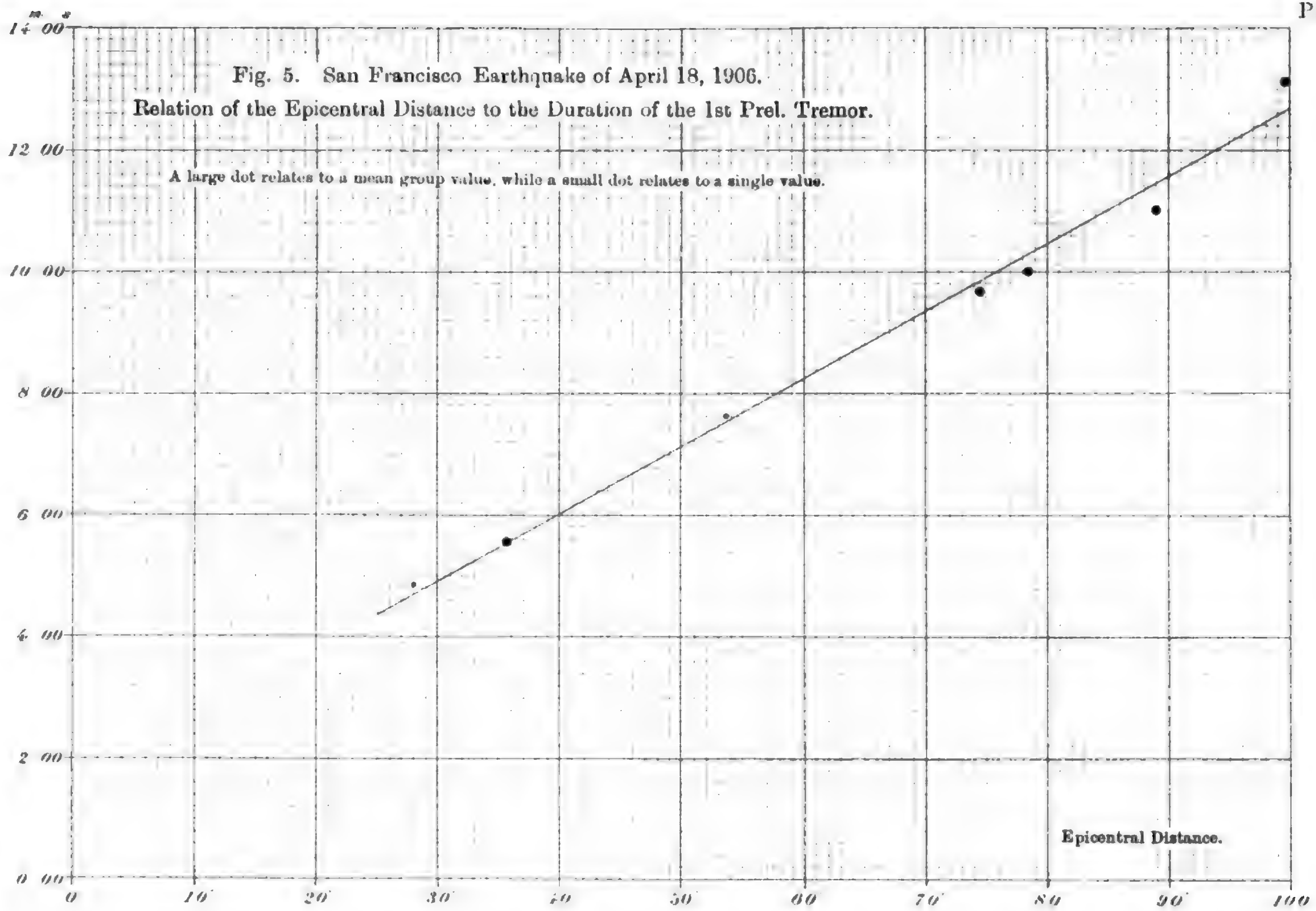


Fig. 5. San Francisco Earthquake of April 18, 1906.

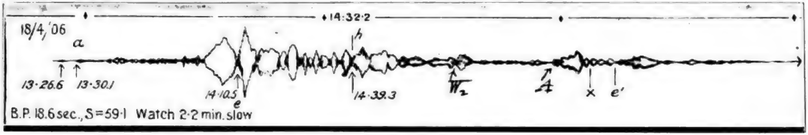
Relation of the Epicentral Distance to the Duration of the 1st Prel. Tremor.

A large dot relates to a mean group value, while a small dot relates to a single value.

SAN FRANCISCO EARTHQUAKE.—RECORD OF MILNE HORIZONTAL SEISMOGRAPH AT WELLINGTON, NEW ZEALAND.

OBSERVER—G. HOGBEN, M.A. [Time, Greenwich mean civil time.]

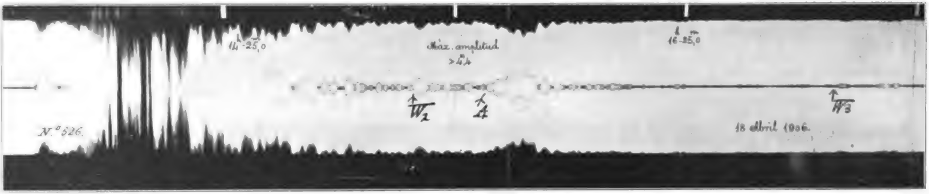
Fig. 6.



The letters denote the waves of the different phases according to Omori's classification: *a*, first phase ("preliminary tremors"); *e*, fifth phase ("long waves"); *e'*, ditto, along the major arc; *h*, eighth phase (probably "transverse waves"); *h'*, ditto, along the major arc. The "repeats" (after successive circuits of the earth) bear the same letters.

SAN FRANCISCO EARTHQUAKE.—RECORD OF MILNE HORIZONTAL PENDULUM SEISMOGRAPH
AT THE MARINE OBSERVATORY OF SAN FERNANDO.

ig. 7.



$=13^h\ 26^m\ 36^s$. The 1st maximum motion, approximately corresponding to the commencement of the principal portion, occurred at $14^h\ 02^m\ 00^s$. The 2nd and largest maximum, which probably corresponded to the 3rd phase of the principal portion, occurring at $14^h\ 10^m\ 30^s$. The 6th phase of the same portion, probably the "transverse" vibration, occurred at $14^h\ 39^m\ 18^s$.

The W_2 motion began at $15^h\ 05^m\ 18^s$; the 1st maximum, which probably corresponded to the commencement of the 3rd phase of the principal portion, occurring at $15^h\ 30^m\ 18^s$. The 2nd maximum occurred at $15^h\ 47^m\ 06^s$.

Comparing the W_1, or the earthquake proper with the W_2 motion, we obtain the following approximate values of the velocities.

Place	Commencement of Princ. Portion.	Commencement of 3rd Phase, Princ. Portion.
San Fernando	4.2 km./sec.	3.7 km./sec.
Wellington	4.8	3.8

These are to be regarded as only gross approximations.

6. The foregoing paragraphs constitute only the preliminary notes on the seismographic observations of the San Francisco earthquake. A full discussion of the transit velocities corresponding to the different phases of the earthquake motion, and the results of the analysis of the seismograms will be given in a future number of the *Publications of the Earthquake Investigation Committee*.

Note on the Transit Velocities of the Guatemala Earthquake of April 19, 1902.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

In the *Proceedings of the Royal Society of London*, Vol. A 76, 1905, Mr. R. D. Oldham* gives an important discussion of the transit velocities of the Guatemala earthquake of April 19, 1902. As, however, Mr. Oldham confines himself to the velocity calculation by the "direct method," I shall here try the calculation by the "difference method" of the velocity of propagation of the 1st preliminary tremor.

The following table, which gives for the different stations the epicentral distance and the time of occurrence and the duration of the 1st preliminary tremor, is taken from Mr. Oldham's paper.

GUATEMALA EARTHQUAKE OF APRIL 19, 1902.

Station	Epicentral Distance.	Time of occurrence. (G. M. T.)	Duration of 1st Prel. Tremor.
		min.	min.
Baltimore	27°.8	2^h 30.1	5.5
Toronto	30.8	30.5	5.0
Victoria, B.C..............	43.0	31.3	5.9
Cordova, Arg..............	52.7	32.1	7.0
Mean	**38.6**	**31.0**	**5.9**
Edinburgh	77.0	36.0	9.5
Bidston (Liverpool)......	77.4	35.0	—
San Fernando	77.6	34.8	8.5

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* R. D. Oldham: "The Rate of Transmission of the Guatemala Earthquake, April 19, 1902."

GUATEMALA EARTHQUAKE.—*Continued.*

Station.	Epicentral Distance.	Time of occurrence. (G. M. T.)	Duration of 1st Prel Tremor.
	°	h min.	min.
Shide (I. of Wight)	78.8	2 35.5	11.4
Kew	79.3	36.2	9.6
Mean	**78.0**	**35.5**	**9.8**
Uccle	82.3	36.0	10.4
Hamburg	84.9	36.3	10.3
Strassburg	85.0	36.2	—
Padua	88.6	36.6	10.6
Florence	88.7	36.6	10.3
Triest	90.2	36.8	12.1
Rome	90.2	37.6	12.7
Quarto Castello	90.4	36.8	10.5
Rocca di papa	90.4	37.0	10.3
Jurjew	91.4	36.8	9.9
Ischia	91.7	37.0	10.6
Catania	93.6	36.7	—
Mean	**89.0**	**36.7**	**10.8**
Nicolajew	100.3	37.0	—
Wellington	102.5	38.0	9.0
Christchurch	104.5	37.2	10.8
Mean	**102.4**	**37.4**	**9.9**
Tokyo	110.4	38.8	15.7
Tiflis	110.7	38.2	18.3
Irkutsk	111.9	42.9	16.2
Cape Town	113.9	38.4	13.2
Mean	**111.7**	**39.6**	**15.9**
Taschkent	121.3	40.2	9.5
Calcutta	142.9	44.0	—
Bombay	144.1	43.5	22.1
Perth, W. A.	149.8	43.8	18.2
Kodaikanal	152.9	—	20.4
Batavia	160.4	43.7	24.3
Mean	**149.3*** **151.8**	**43.8**	**21.3**

* 149.3 is the mean distance obtained by omitting Kodaikanal, and 151.8 that obtained by omitting Calcutta. These two values are to be used respectively for the time of occurrence and the duration of the 1st preliminary tremor.

I have divided the 34 stations contained in the preceding table into 7 groups, the relation between the mean values of the epicentral distance and the time of occurrence being illustrated in the accompanying figure (Pl. XIV). From the latter it will be seen that, within the limits of the distance under consideration, the time of earthquake occurrence increased linearly with the distance. Assuming, therefore, an equation of the 1st degree between the time and the distance, and calculating by the method of Least Squares, we obtain

$$v_1 = 16.02 \; km. \text{ per sec.*}$$

This value of v_1 is 2 *km.* greater than that found for the San Francisco earthquake, as given in the preceding article.

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* The value of v_1 previously obtained for this earthquake by Dr. A. Imamura was 15.6 *km.* per sec.

The Calabrian Earthquake of Sept. 8, 1905, observed in Tokyo.

By

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1. Pl. XV gives the EW, NS, and vertical components of motion due to the disastrous Calabrian earthquake of Sept. 8, 1905, observed in the University compound, (Hongo), Tokyo; the magnifying ratios in the three diagrams being respectively 15, 20, and 12. The details of construction of the two horizontal component instruments,* which are nearly alike to one another, are as follows:—

Vertical distance between the points of suspension and of support = 2 metres.

Effective length of the strut, or the horizontal distance between the point of support and the steady axis = 1 metre.

Weight of the heavy bob = ...	17.4 kg. (EW). 46.0 kg. (NS).
Natural Oscillation Period	61.5 sec. (EW). 48.5 sec. (NS).

The vertical instrument, which is one of Gray-Ewing type, has the following specifications:

Length of the vertical spiral springs = 1.2 metre.

Horizontal distance between the centre of the steady mass and the pivot = 1.2 metre.

Weight of the heavy bob = 9 kg.

Natural Oscillation period = 6.0 sec.

The time of commencement of the earthquake motion was 1^h 56^m 09^s (G.M.T.). In the following descriptions of the seismograms, T and $2a$ denote respectively the complete period and the double amplitude of motion.

---

* These are the long-period horizontal pendulums described in the *Publications*, No. 5, with some changes in the weight of the steady mass and the multiplication ratios.

2. *EW Component.* Total duration=3 hours. The commencement was very small, and slightly uncertain.

1st Preliminary Tremor. Duration$=10^m\ 25^s$. For the first $2^m\ 0^s$, the motion was very small. The subsequent motion was larger and nearly uniform:—T=7.7 sec., max. $2a=3.3$ mm, there being also traces of small vibrations.

2nd Preliminary Tremor. Duration$=11^m\ 49^s$. The motion was greater during the first $6^m\ 20^s$ than during the rest of this phase:—

$$\left\{\begin{array}{rl} T= & 6.4 \text{ sec., max. } 2a=0.1 \text{ mm.} \\ & 8.3\ \ ,,\ ,\ \text{small.} \\ & 11.6\ \ ,,\ ,\ \ ,, \end{array}\right.$$

Principal Portion. [1st and 2nd phases.] Duration$=10^m\ 43^s$. During the first $5^m\ 48^s$, the motion was small:—T=21.2 sec., max. $2a=0.6$ mm., there being also small vibrations of T=8.7 and 6.4 sec. For the next $2^m\ 25^s$, there were 3 small slow vibrations:—T=48.3 sec., max. $2a=0.05$ mm, superposed by small vibrations of T=8.5 sec. For the remaining $2^m\ 29^s$, there were 4 larger and nearly equal vibrations:—T=37.3 sec., max. $2a=0.13$ mm; there being also some small vibrations. [3rd phase.] Duration$=9^m\ 39^s$. During the first $2^m\ 8^s$, the motion consisted of 4½ regular vibrations:—T=28.5 sec., the 4th having the max. $2a$ of 0.35 mm. For the next $2^m\ 38^s$, the vibrations were smaller and quicker:—T=21.1 sec., max. $2a=0.24$ mm. For the remaining $4^m\ 57^s$, the vibrations became again quicker:—T=14.5 sec., the two max. $2a$'s of 0.45 and 0.50 mm. occurring respectively $5^m\ 39^s$ and $8^m\ 54^s$ after the commencement of this phase. There were also some traces of vibrations of T=28.8 sec. [4th phase]. During the first $5^m\ 25^s$, the motion was large:—T=17.7 sec., max. $2a=0.21$ mm; T=11.8 sec., max. $2a=0.20$ mm. During the remaining $10^m\ 53^s$ of this phase, the motion was smaller and nearly uniform:—$T=11.1$ sec., max. $2a=0.12$ mm; $T=16.9$ sec., max. $2a=0.08$ mm. [5th, etc. phases]. The motion was much smaller. Toward the end, $T=13.9$ sec.

The W_2 vibrations, or the earthquake movements propagated along the major arc of the earth, appeared at $3^h\ 47^m\ 10^s$ (G.M.T.)

3. NS Component. The commencement was very small and slightly indistinct.

1st Preliminary Tremor. Duration=about $10^m\ 57^s$. For the first 1^m, the motion was very small. The subsequent motion was nearly uniform :—$T=6.0$ sec., max. $2a=0.03$ mm, mixed with some vibrations of $T=11.3$ sec.

2nd Preliminary Tremor. Duration$=9^m\ 44^s$. The motion was greater near the commencement :—$T=7.0$ sec., max $2a=0.08$ mm; $T=10.3$ sec., max. $2a=0.12$ mm.

Principal Portion. [1st and 2nd phase.] Duration$=11^m\ 30^s$. During the first $9^m\ 44^s$, the motion was nearly constant:—

$$\left\{\begin{array}{llll} T=14.9 \text{ sec.,} & \text{max.} & 2a=0.06 & \text{mm;} \\ \text{,,}= 8.0 & \text{,} \quad \text{,,} & =0.05 & \text{,, ;} \\ \text{,,}= 4.0 & \text{, small.} & & \end{array}\right.$$

During the remaining $1^m\ 47^s$, there were 2 and half well-defined vibrations:—$T=42.8$ sec., max. $2a=0.1$ mm. [3rd phase.] Duration$=15^m\ 18^s$. During the first $1^m\ 29^s$, there were 2 and half well-defined and nearly equal vibrations:—$T=35.7$ sec., max. $2a=0.22$ mm. For the next $2^m\ 14^s$, the vibrations became quicker:—$T=26.8$ sec., max. $2a=0.33$ mm. For the next $1^m\ 35^s$, the motion was smaller:—$T=19.0$ sec., max. $2a=0.25$ mm. For the next $1^m\ 11^s$, there were 2 slow small vibrations:—period$=35.5$ sec., max. $2a=0.09$ mm, superposed with small movements of $T=10.1$ sec. Thereafter the motion became much quicker and active, the vibrations during the next $2^m\ 31^s$ being $T=15.1$ sec., max. $2a=0.35$ mm, mixed with slower vibrations of $T=30.2$ sec., max. $2a=0.40$ mm. For the next $1^m\ 42^s$:—$T=25.5$ sec., max. $2a=0.33$ mm. For the next $1^m\ 51^s$, the motion became again quicker:—$T=13.9$ sec., max. $2a=0.13$ mm. During the remaining $9^m\ 28^s$, the period remained nearly constant:—$T=16.2$ sec., max. $2a=0.43$ mm, mixed with some small vibrations of $T=10.3$ sec. [4th, etc. phases.] During the first $8^m\ 20^s$:—$T=11.3$ sec., max. $2a=0.08$ mm; $T=19.7$ sec., max. $2a=0.09$ mm.

End Portion. The vibrations had a T of 13.2 sec., there being also some vibrations of $T=17.1$ sec.

The W_2 vibrations which appeared at $4^h\ 06^m\ 26^s$ (G.M.T.), were small but well defined:—$T=18.5$ sec., max. $2a$=small.

4. *Vertical Component.* The motion began with small quick vibrations. At $2^h\ 32^m\ 57^s$ (G.M.T.), there appeared small slow vibrations continuing for about 10 min. $7^m\ 20^s$ later on the movements became more distinct :—$T=15.2$ sec., max. $2a=0.03$ mm.

Appendix. The observations of the Calabrian earthquake at Osaka and Mizusawa were as follows:—

Osaka (*EW*).

Total Duration$=1^h\ 24^m$. Time of commencement$=1^h\ 56^m\ 31^s$.

1st Prel. Trem.	Duration$=10^m 15^s$;	$T=6.6$ sec.;	max. $2a=0.2$ mm.
2nd „ „	„ $=11\ 10$;	„ $=6.7$ „ ;	„ „ $=0.7$ „

Principal Portion:—

1st and 2nd phases.	Dur.$=7^m 10^s$;	$T=20.0$ sec.;	max. $2a=0.4$ mm.
3rd phase.	„ $=8\ 25$;	„ $=21.9$ „ ;	„ $=0.5$ „
4th „	„ $=8\ 30$;	„ $=17.1$ „ ;	„ $=0.4$ „
5th „	„ $=9\ 00$;	„ $=12.7$ „ ;	„ $=0.1$ „
6th „	„ $=8\ 10$;	„ $=15.4$ „ ;	„ $=0.5$ „

7th phase. Dur. = 7 45 ; T = 13.8 sec.; max $2a = 0.2$ mm.

End Portion. „ = 14.4 „ ; „

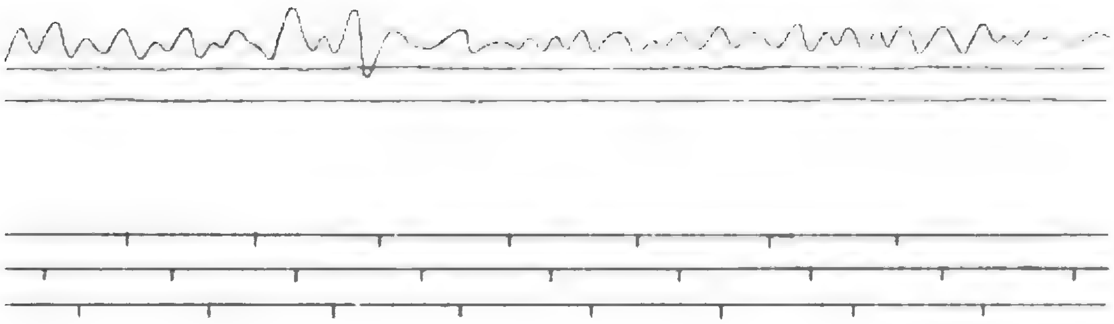
Mizusawa.

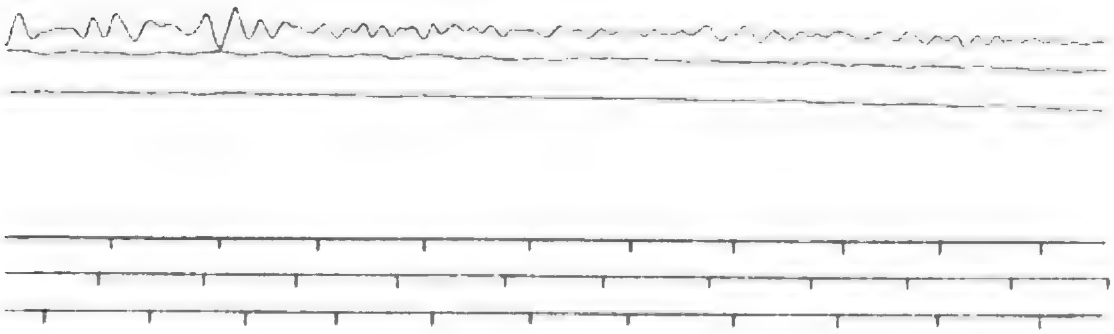
Time of commencement = $1^h\ 56^m\ 12^s$.

$\left\{\begin{array}{l}\text{Max. } 2a = 0.03 \text{ mm. (EW Component),} \\ \quad „ \quad = 0.09 \quad „ \quad \text{(NS} \qquad „ \qquad \text{).}\end{array}\right.$

The instruments at Osaka and Mizusawa are horizontal pendulums of portable form, the natural oscillation period at Osaka being about 28 sec.

PL. XV.





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Preliminary Note on the Formosa Earthquake of March 17, 1906.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** The Island of Formosa is preëminently an earthquake country and has been visited within the last 2 years between April 1904 and April 1906, by no less than 4 destructive shocks. From the time of Teiseikō, a Chinese general who occupied the island in the middle of the 17th century at the downfall of the Min dynasty, there were, up to 1906, eighteen severe earthquakes, as follows.

NO.	DATE.	LOCALITY.	REMARKS.
1	Jan. 21, 1655.	Tainan.	
2	———, 1660.	,,	
3	Nov. 1, 1720.	,,	
4	Jan. 5, 1721.	,, …………………	Many people killed; mud and water ejected. Shocks continued for more than 10 days.
5	Jan. 27, 1736.	Tainan, Kagi, Shōka…	Many people killed. The weather was fine.
6	Dec. —, 1776.	Kagi……………………	Great many people killed.
7	July 20, 1792.	Kagi……………………	Fires broke out after the earthquake, more than 100 people killed.
8	July —, 1815.	Giran.	
	Oct. —, 1815.	Tansui.	
10	———, 1816.	Giran …………………	Houses destroyed. The ground was cracked, and in some places convulsed.
11	Nov. —, 1840.	Toroku…………………	Houses destroyed. Landslips took place.

NO.	DATE.	LOCALITY.	REMARKS.
12	June 6, 1862.	Tainan, Kagi, Shōka...	This was a very great earthquake, and in Kagi more than 1000 persons were killed. The mount Daisen was much cracked.
13	Dec. 18, 1867.	Keelung	Great destruction in the harbour of Keelung, where several hundreds of people were drowned by the sea waves. Enormous landslips took place.
14	June 7, 1901.	Giran.	
15	April 24, 1904.	Toroku to Banshoryō...	3 persons killed, 13 wounded.
16	Nov. 6, 1904.	Toroku, Kagi, Ensuikō.	145 ,, ,, , 148 ,, .
17	March 17, 1906.	Kagi, Toroku.............	1266 ,, ,, , 2476 ,, .
18	April 14, 1906.	Kagi, Ensuikō...........	15 ,, ,, , 87 ,, .

Of the 18 earthquakes given in the above table, 13 originated in the south-western part of the island, namely, in the Prefectures of Toroku, Kagi, Ensuikō, and Tainan. The 5 other earthquakes shook the north-eastern part of the island, their origins being submarine.

In the *Reports* (Japanese) *of the Imperial Earthquake Investigation Committee*, No. 54, the present author, who visited Formosa in Nov. 1904, has given a full account of the two destructive earthquakes of that year, together with the results of the seismographical measurements made at the different observatories in the island.

EARTHQUAKE OF MARCH 17, 1906.

2. ***Damage.*** The earthquake of March 17, 1906, at 6^h 42^m 30^s A.M.,* was the severest which shook Formosa in recent times, being even more destructive than the well-known great shock of June 6, 1862. The numbers of the houses damaged and the casualties were as follows :—

---

* Given in 2nd Normal Japan Time, or that of longitude 120° E of Greenwich.

Number of dwelling houses totally destroyed	7,284
,, ,, ,, ,, partially ,,	30,021
,, ,, persons killed	1,266
,, ,, ,, wounded	2,476

As far as the loss of life is concerned, this earthquake was, among the recent Japan shocks, only second to the great Mino-Owari catastrophe of 1891.

Immediately after the earthquake of March 17, 1906, I proceeded again to Formosa and was able, amongst other things, to compare the seismic effects on this occasion with those in Nov. 1904. One specially interesting feature in this earthquake was the formation of remarkable faults, which are described in § 4.

The heavy amount of the casualties was, in a great measure, due to the weakness of the native dwelling houses, which mostly have no capacity of resisting earthquake shocks, being built of *dokaku*, or sun-dried mud blocks of dimensions $22 \times 33 \times 9\frac{1}{2}$ cm., loosely cemented with a mortar of mud, at best mixed with a small quantity of lime. The consequence of such a bad method of construction, joined to the heaviness of the roof, is that the native houses are, at the occurrence of a violent shock, at once shattered to pieces, leaving little time for the people to escape. The easiness with which the *dokaku* houses are overthrown may be seen from the fact that the town of Dabyō was almost entirely levelled to the ground with the exception of the Sub-Prefectural Office, a brick one-story building with a two-story tower, which suffered no severe damage except some cracks in walls and the falling down of part of the roof tiles. Framed timber structures resist earthquake shocks infinitely better than the *dokaku* houses, but they are generally exposed, when old, to a great danger from the ravages of white ants, which literally eat up the wood.

Fig. 9 shows the ruined condition of a native temple, Masobyō, in the town of Shinkō, the destruction of the building being very complete. Fig. 8 gives a view after the earthquake of the Sub-Prefectural Office in the same town, a wooden structure with plastered walls, which was very severely damaged, due mainly to the vibration of the front tower, but was not overthrown to the ground.

3. Isoseismals. The earthquake was felt all over the Island, the three isoseismal lines in Fig. 1 (Pl. XVI) giving approximate boundaries of the areas defined as follows :—

(1) *Area of violent motion*, in which the damage was considerable.

(2) *Area of severe motion*, in which occurred more or less such damage as landslips, cracks of the ground, partial or total destruction of a few buildings, etc.

(3) *Area of moderate motion*, in which the shock was moderately strong, so that some furnitures were overthrown, pendulum clocks were stopped, etc.

Different from usual cases of seismic disturbances in Formosa the longer axes of the isoseismal areas, especially, Nos. 1 and 2, are not parallel to the length of the Island, evidently due to the fact that the fault and the epifocal zone was oblique to the latter.

The area (1) of violent motion was about 50^{km} in length, from the vicinity of the town of Baishikō on the east to the city of Shinkō on the west, and about 30^{km} in width from the vicinity of the city of Kagi on the south to that of the village of Tarimu on the north. From the limited extension of the area of the severe motion, it may be inferred at once that the earthquake centre was not deep below the surface, as was in fact indicated by the formation of the faults.

4. Faults. (See Pl. XVII.) The main fault line is most markedly shown at its eastern end, where it crosses the road leading from the town of Taihorin to Baishikō, at about 1^{km} from the latter town. The fault runs here in the direction of N 75° E and S 75° W, the south side being depressed 6 feet and relatively sheared 6 feet westwards. Fig. 5 gives a general view of the fault, the left-hand (south) side being depressed in such a way that it curves down toward the plane of discontinuity. Fig. 4 shows how the road was cut off and displaced at its intersection with the fault. The small village of Bishō, under which the fault passed, was completely destroyed. The western continuation of the fault passes across a hill spur and appears again to the south of the village of Kaigenkō, at about 1^{km} from Bishō. The fault then runs in a mean direction of N 75° E to S 75° W and crosses the river Sanjōkei, at 5^{km} from Kaigenkō and about 1^{km} to the SW of the village of Maenryō, producing a 4 feet dislocation of the river bed. Then it becomes nearly SW in direction and passes between the villages of Tensanshikiaku and Kasanshikiaku, meeting finally to the south of the latter the branch fault of Chinsekiryō. This second fault starts at about half a kilometre to the west of the village last named, on the top of a gently sloping hill of hard clay, and manifested itself first as a remarkable deep crack of 2 feet width, the depth ascertained with a bamboo stick being 11 feet. (See Fig. 6.) This fault is nearly in the E W direction and its western continuation passes through cultivated grounds, cutting at right angles a series of potato field ridges, which latter suffered a relative horizontal displacement amounting to the interval between two successive ridges, so that each of the latter became, after the earthquake, contiguous to its former neighbour. The fault then runs through the puddy fields, to the north of the village of Tōseiko, finally reaching the city of Dabyō, beyond which the disturbance of the ground ceases to be apparent. The railroad, which runs in an N–S direction was much damaged between Dabyō and Kagi, especially at its intersection with the fault, 8 rails being considerably bent and a number of rail joints torn apart. The length of the main, or Baishikō, fault is about 11^{km}, while that of the branch, or Chinsekiryō, fault is a little over 4^{km}, the whole length between the Dabyō and Baishiko ends being $13\frac{1}{2}^{km}$.

As stated before, at the eastern extremity of the main fault the south-side was depressed and sheared westwards. But, along the whole rest of the fault the relation was reversed, and the depression was invariably on the north (or NNW) side, the shear being always eastwards. The maximum amount of the eastward shear was 8 feet and occurred at the village of Kaigenkō; while the maximum northward depression of 4 feet occurred at the last named place, and also at and near the crossing of the fault with the Sanjōkei river. Along the Chinsekiryō fault, the depression was also always on the north side, and the shear, whose maximum amount was 5 feet, was eastwards. In this case, the vertical dislocation was slight and less than 1 foot, being often indicated only by a gradual depression which caused the waters in the puddy fields to be collected on one side of the line of disturbance, leaving the other side dry.

To the west of Dabyō there was no surface manifestation of tectonic disturbances. But it seems probable that there exists an underground continuation of the fault for about 12^{km} in the direction of west slightly south, as far as the vicinity of the city of Shinkō. Along the zone about this imaginary fault, which is marked in Pl. XVIII by a dotted line, there was an ejection of large quantity of sand and water. Especially, in the vicinity of the villages of Tanshiken and Saikōseki, the ejected sand reached a thickness of more than two feet and covered wide areas sometimes half a kilometre or more in width. (See Fig. 7.) The enormity of water ejection in these places may be judged from the fact that the police authorities, who tried to rescue people from under the ruined houses, were in some instances prevented from immediately approaching the latter, owing to the large quantity of mud water which flooded the surrounding grounds. The total length of the fault between Baishikō on the east and Tanshiken on the west is $25\frac{1}{2}^{km}$.

8. Relation to the Faults of the Direction of (Vibratory) Motion. Fig. 3 (Pl. XVIII.) indicates the general course of the faults, the directions of the (vibratory) motion at the different places, and the boundary of the area of the severest shock. This latter area is slightly different from that bounded by the line (1) in Fig. 1, and includes those towns and villages, in each of which more than 50 dwelling houses were completely destroyed or more than 15 persons were killed.

The directions of motion at the different places in this meizoseismal area determined from overthrown bodies, were as follows :—

Kagi	Toward	ESE.
Shinkō	,,	ENE.
Suigiuseki	,,	SE.
Seiho	,,	E.
Dabyō	,,	E slightly S.
Baishiko	,,	SSE.

Thus it will be seen that the earthquake motion in the meizoseismal area was not perpendicular to the fault zone, but was, on the whole, directed from the western to the eastern end of the latter, in the same sense as the shear of the depressed side, with the exception of the eastern extremity of the main fault. This seems to indicate that the tectonic disturbances were the result of the existence in this part of the earth's crust of a pressure or shearing forces in a driection nearly transverse to the longer axis of the island of Formosa, which finally produced the faults, such that the first shock or sudden movement of the ground was westwards, and the counter or greatest one eastwards. Probably both sides of the fault zone were displaced eastwards, the shear of the depressed side being the differential amount due to the greater eastward displacement of the latter.

The disturbances of the ground along the two faults above described were similar to those observed in other cases, the depression and the horizontal shear being generally combined. There were also the usual *secondary shear cracks,** whose inclination to the course of the dislocation zone was on the average about 43°. At some places along the main fault there were marked forcing up of the ground, due to the coexistence of compression. On the other hand, the wide crack which appeared near Chinsekiryō, was the result of a tension or a tendency to tear ashunder the two sides of the fault plane.

6. *Probable Eastward Extension of the Fault.* The boundary of the meizoseismal area given in Pl. XVIII. is evidently not complete and represents only the western half, the eastern half including mountainous regions inhabited by the savages, whence we could get no earthquake reports. Thus it is extremely likely that the main fault did not end at the vicinity of Baishikō, but was continued eastwards amoung the mountains for a further distance of 20 or 25^{km}. This supposition consistently explains why the depression and shear phenomena at the eastern end of the Dabyo-Baishiko fault zone were opposite to those along the rest of the latter. The fact was probably as follows :—the fault had an extension of about 50^{km} and its most central point was between Bishō and Kaigenkō, the amount of the disturbances being greatest near these two places ; further, along the western half of the zone in question the ground on the north side was depressed and sheared eastwards, while along the eastern half the ground on the south side was depressed and sheared westwards. (See the next Article.)

---

* See the *Bulletin*, No. 1, p. 13.

The most central point of the epifocal zone as ssumed above may probably be taken to be between the villages of Bishō and Kaigenko, say, at

$$\begin{cases} \textit{Longitude}, & 120^\circ \ 32' \ \text{E.} \\ \textit{Latitude}, & 23^\circ \ 35' \ \text{N.} \end{cases}$$

7. *Duration of the Preliminary Tremor.* The approximate position of the centre of the earthquake may also be inferred from the duration (y) of the preliminary tremor recorded by Omori Horizontal Pendulums at the different meteorological observatories in Formosa. The epicentral distance (x) in the following table have been calculated by the formula*

$$x^{km}=7.27 \ y^{sec}+38^{km}.$$

Earthquake of March ,17, 1906.

Place.	Duration of Prel. Tremor $=y$.	Epicentral Distance $=x$.
Taihoku	27.5 *sec.*	238 *km*
Taichu	9.0	104
Tainan	8.7	101
Hokoto	11.5	122

---

* The *Publications*, No. 13.

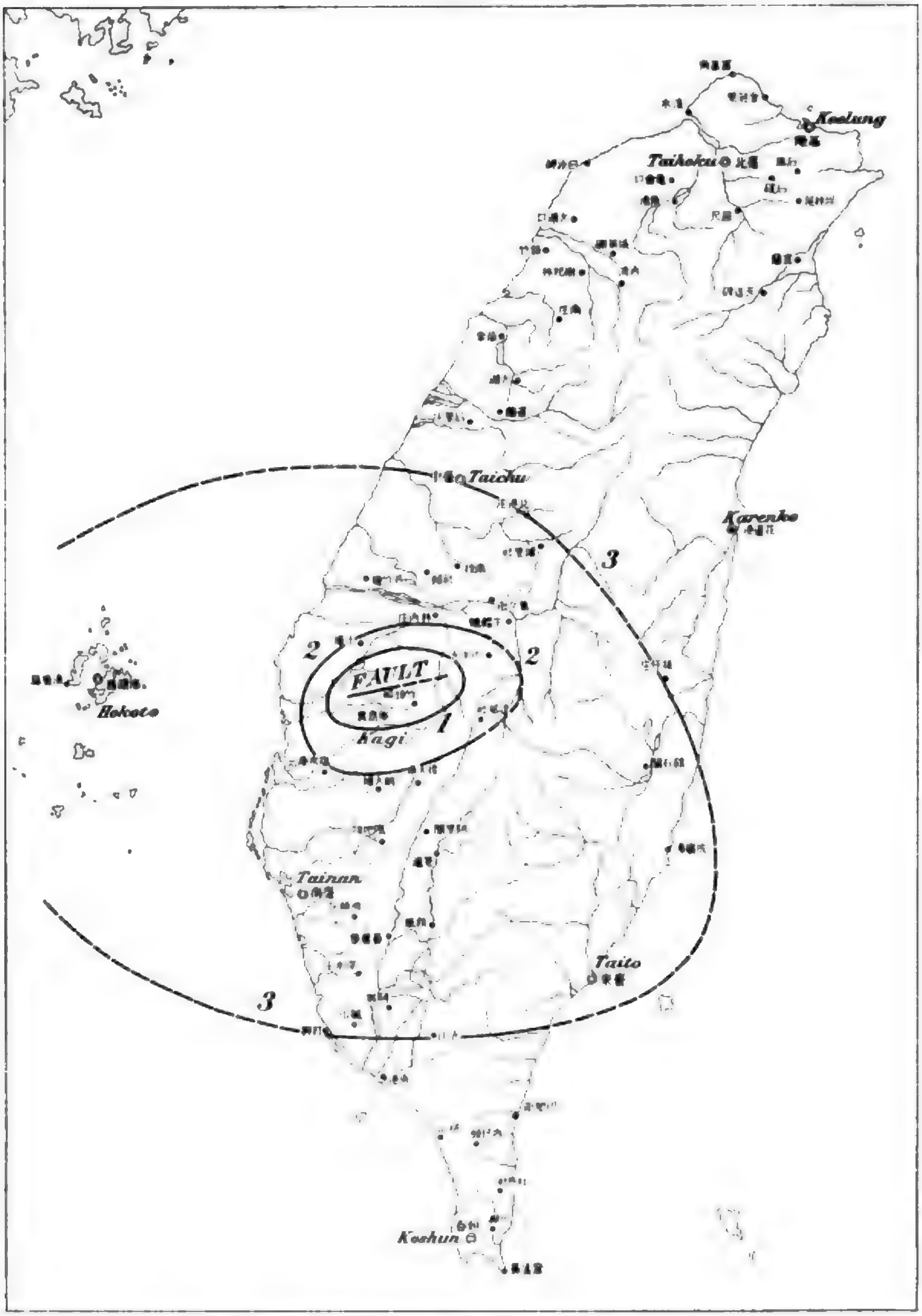
The circles drawn upon a map of Formosa about these four places with radii respectively equivalent to the calculated values of the epicentral distances enclose an area, whose centre roughly coincides with the region midway between the cities of Dabyō and Baishiko.

8. ***The Two Severe Earthquakes in 1904.*** The earthquake on the early morning of Nov. 6, 1904, at 4h 25m, caused a large amount of damage in the three prefectures of Toroku, Kagi, and Ensuiko, the casualties and the number of houses damaged being as follows.

Prefecture.	Casualties.		Number of Houses damaged.		
	Killed.	Wounded.	Totally destroyed.	Greatly damaged.	Slightly damaged.
Kagi	133	132	425	1021	1453
Toroku	10	16	62	60	517
Ensuiko	2	0	3	4	5
Sum	145	148	490	1085	1975

Thus the number of the killed was nearly equal to that of the wounded, which is much different from what is usually the case in which the number of the wounded much exceeds that of the killed. According to the above table, 1 person was killed for every 3.4 houses totally destroyed. This ratio is much smaller than what takes place in Japan proper: thus, for instance, in the great Mino-Owari earthquake of 1891, there was 1 person killed for every 11 houses totally destroyed. These peculialities in the Formosa earthquake are evidently due to the bad construction of the native houses in the island, as remarked in § 2. As can easily be demonstrated, a very bad material of construction, which possesses no tensile strength, has a very serious defect, namely, it causes

Fig. 1. Map Showing the Isoseismal Lines of the Earthquake of March 17, 1906.


Keelung
Taihoku
Taichu
Karenko
3
2
2
FAULT
1
Kagi
Hokoto
Tainan
Taito
3
Koshun

○ ············ Meteorological observatory.

● ············ Station for Precipitation observation.

Fig. 2. Map. Showing the Actual Trace of the Baishikō and Chinsekiryō Faults.

(Towns, villages, rivers, and railroads only are shown.)

The red shade is the depressed side, the arrow indicating the direction of shear of the latter.

The figure in the shade gives the amount of depression, while that at the point of the arrow indicates the extent of shear.

The eastern continuation of the main Fault is lost among the mountains.

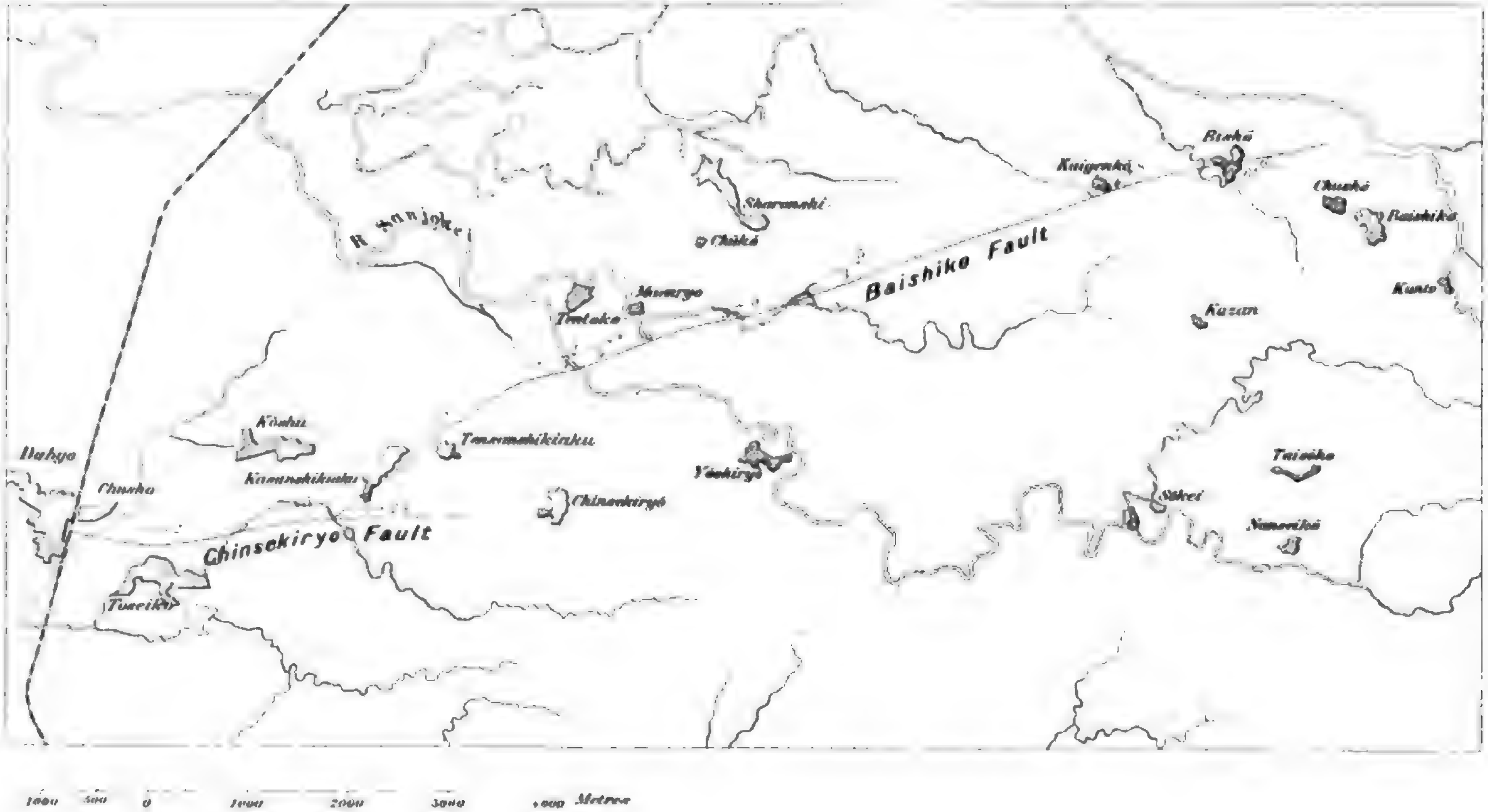
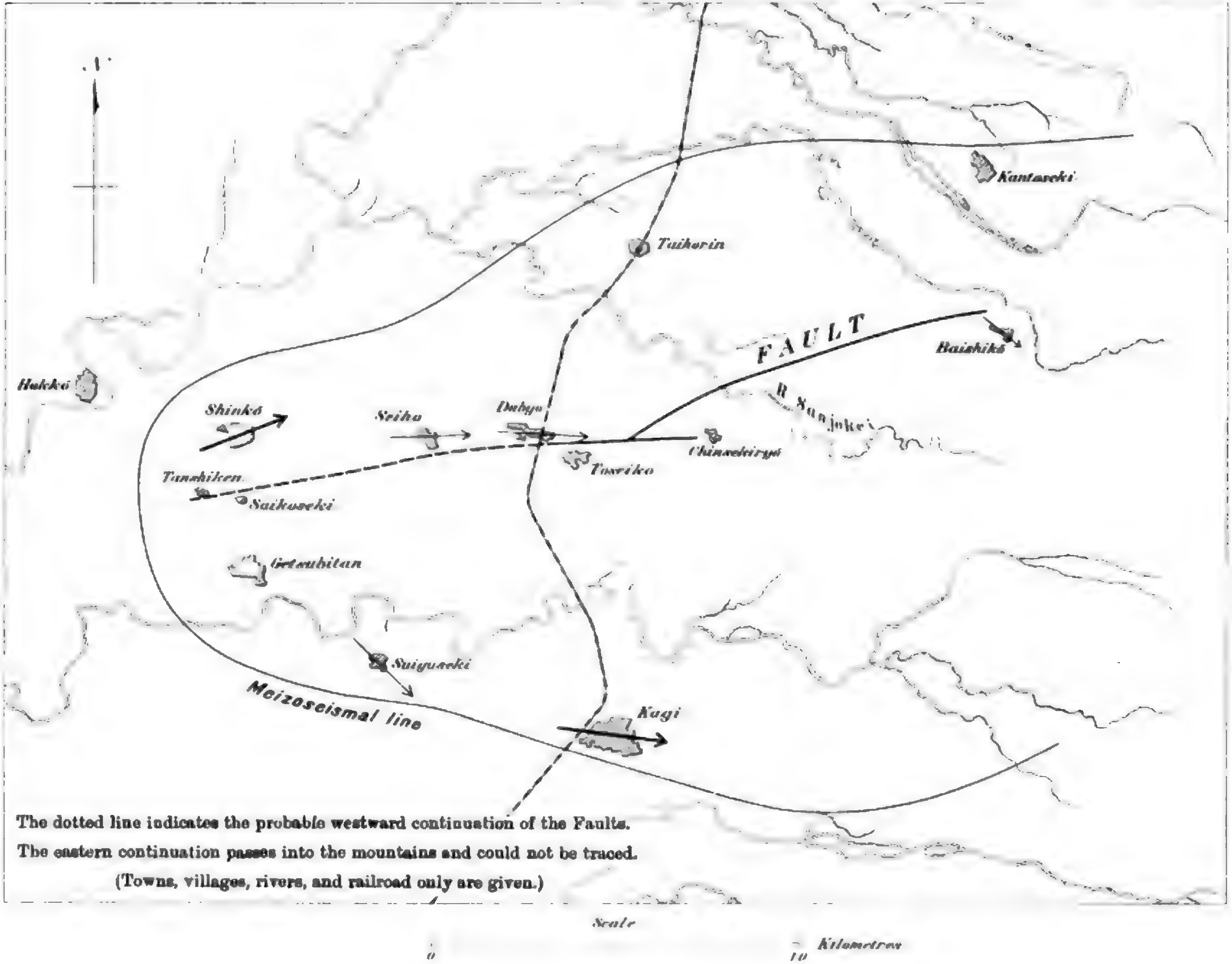

Baishiko Fault
Chinsekiryō Fault
Bisho
Chusho
Baishiko
Kunto
Kuzan
Shinei
Taisiko
Shoranaki
Chiko
Muvaryo
Toteko
Yoshiryo
Chinsekiryō
Kōshu
Dahyo
Chusko
Tueiko
1000 500 0 1000 2000 3000 4000 Metres

Fig. 3. Map Showing the Meizoseismal Line, the General Course of the Faults, and the Directions of Motion at the Different Places.


Kantaseki
Taiherin
FAULT
Baishiko
Hakko
R. Sanjokei
Shinko
Seiho
Dabyo
Chinseikiryo
Toseiko
Tanshiken
Saikoseki
Getsubitan
Suiyuseki
Kagi
Meizoseismal line
Scale
0
10
Kilometres

The dotted line indicates the probable westward continuation of the Faults.
The eastern continuation passes into the mountains and could not be traced.
(Towns, villages, rivers, and railroad only are given.)

The Baishiko Fault.

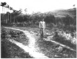


Fig. 1. View of the [illegible]-Baishiko Road; the foreground (southern side) sank [illegible] feet and was displaced [illegible] feet westwards. (x) Mark the former continuation of the road.

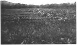


Fig. 2. General view of the Fault Trace south-east. The left-hand (southern) side was depressed 4 feet, sloping down towards the fault line.

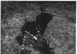


Fig. 6. [illegible] Fault; a wide crack formed on a flat hill-top ground, the depth being more than 12 feet. A 6 ft. rule placed across the opening shows the width.

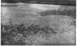


Fig. 7. Great Sand Eruption, near the village of [illegible]. The cultivated fields were covered with sand to a depth of 4 feet.

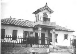


Fig. 5. The New Sub-Prefectural Office, [illegible], showing the effects of vibration of the [illegible] tower. The building was of wood, with plastered walls.

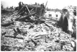


Fig. 6. The native Shin Temple in the city of [illegible]. The building was completely destroyed owing to bad masonry and weakness of wooden timbers on account of ravages of white ants.

the seismic stability of the wall to be nearly independent of the thickness: very thick walls of the Formosan *dokaku*, therefore, being thrown down by earthquake shocks quite as easily as thin ones. Had the same earthquake taken place in small towns of Japan proper the casualties would have been very slight. The intensity of motion in the most strongly shaken area was nearly half of that at Gifu or Ōgaki on the occasion of the Mino-Owari earthquake.

In Formosa there are also a large number of houses or cottages, built of bamboo, with very light roofs. These were of course not damaged by the earthquake. Wooden buildings in ordinary Japanese style also received no particular damage, except cracking of plastered walls and the disturbances of roof tiles.

The area of destructive motion was a narrow zone, whose length and breadth were about 57 and 23^{km} respectively. This zone, whose longer axis was in a NNE-SSW direction, stretched from the vicinity of the town of Toroku on the north to the vicinity of the village of Shin-eisho in the south ; the shock having been strongest in the district between the towns of Shinko and Kagi, at the middle of the area under consideration, or at about *lat.* 23°30′ N, and *long.* 120°26′ E.

The earthquake of April 24, 1904, at 2^{h} 39^{m} P.M. which also disturbed the south-western part of Formosa, was not so violent as that of Nov. 6, but its area of disturbance was much larger, and the zone of severe motion, whose length and breadth were 123 and 32^{km} respectively, ran in a NNE-SSW direction from the vicinity of the town of Toroku on the north to the vicinity of Banshoryo and Hozan on the south.

The position of the centre of each of the two earthquakes of April 24 and Nov. 6, 1904, may also be determined from the duration of the preliminary tremor observed at the different places, the epicentral distance being calculated by the same formula as that given in § 7.

Earthquake of April 24, 1904.

Place.	Duration of Prel. Tremor $=y$.	Epicentral Distance $=x$.
Taihoku	28.7 *sec.*	246 *km.*
Taichu	11.4	120
Taito	12.8	131
Hokoto	12.7	130

Earthquake of Nov. 6, 1904.

Place.	Duration of Prel. Tremor $=y$.	Epicentral Distance $=x$.
Taihoku	28.8 *sec.*	246 *km.*
Taichu	11.2	119
Tainan	8.3	98
Taito	15.5	150
Hokoto	9.0	103

The circles drawn, for each of the two earthquakes, about the different places with the radii equivalent to the corresponding epicentral distances enclose an area, whose centre approximately coincides with the middle of the meizoseismal zone already mentioned.

9. Relation of the Earthquake of March 17, 1906, with those in 1904.* The violent earthquake of Nov. 6, 1904, was small in area, and its epifocus had a length of only 57^{km}, nearly coinciding with the northern half of that of the earthquake of

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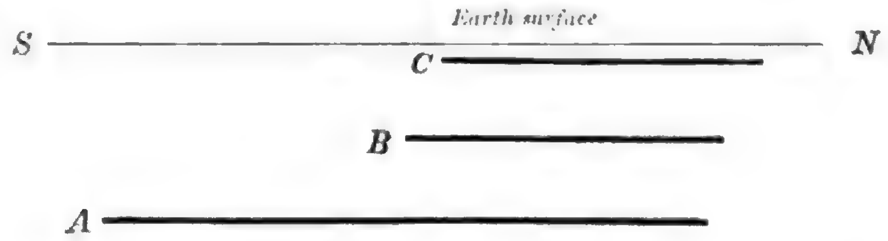
* The times are given in that of *long.* 120° E. of Greenwich.

April 24 in the same year, whose epifocal zone had a length of 123^{km}. Thus the April earthquake was, in magnitude, 2 or 3 times greater than the November one, while the intensity of motion in the latter was very much higher than in the former, the difference in the amount of the damage and casualties being also considerable.* It is evident, therefore, that the focus of the 1st earthquake was deep, while that of the 2nd was shallow. The two seismic foci may diagrammatically be represented by the two lines

Fig. 10.



A and *B* respectively (Fig. 10). It is probable that the second earthquake was in some way connected with the first; and, as the direction of the maximum displacement at the different places was in the 2nd earthquake generally directed *toward* the epifocus, which implies an initial outward motion, the cause of these two shocks was probably the sudden formation in an N-S direction of an underground cavity, the 2nd earthquake being due to an upward extension of the latter at its northern part. Thus it was to be inferred that the earthquake of Nov. 6, 1904, was only a disturbance which marked an intermediate stage in the development of the seismic activity along the zone under consideration, leaving a possibility of the occurrence of a final destructive shock, whose origin would be quite near the surface and at the northern end of the epifocal zone of the earthquake of April 24, 1904.

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* These two earthquakes are Nos. 15 and 16 given in the Table, § 1.

From these considerations, and also because such severe but local shocks as those which happened in the south-western part of Formosa, often take place successively at neighbouring places in the course of a few years, I stated at the time of my visit to Formosa in the end of 1904 that the districts about Kagi might be visited after some years by a third shock, against which, however, it would be possible to make structures earthquake-proof, provided proper cares be taken in the building.* My anticipation was, in a measure, fulfilled by the occurrence of the earthquake of March 17, 1906, although its epifocal zone was at right angles to those of the two preceding ones.

After the occurrence of the destructive shock of March 17, accompanied by the formation of remarkable faults, it was to be expected that the next severe shock, if any, would rather have its origin displaced southwards and at a greater depth such that the surface intensity would not be so very violent. I have stated this view in a Tainan daily newspaper, the "Tainan Shinpō," of April 13, 1906, and on the next day, April 14, there took place an earthquake, nearly as extensive as that of March 17, the origin however, having been displaced about 10 miles towards the south, so that the city of Kagi was now at the northern limit of the area of destructive motion. The position of the origin of the earthquake of April 14, which was accompanied by no surface fault, was approximately

$$\begin{cases} \textit{Longitude}, & 120^\circ\ 30'\ \text{E} \\ \textit{Latitude}, & 23^\circ\ 25'\ \text{N}. \end{cases}$$

10. ***Periodic Repetitions of Strong After-shocks.*** The violent earthquak of March 17, 1906, was followed by numerous after-shocks, attended by the usual phenomena of sound. What was very peculiar in this case was the abnormal severity of many of these subsequent shocks, some of which, like the severe earthquake of April 14, was in reality not an after-shock at all, but rather a separate manifestation at a different place of the same seismic activity which caused the first great shock. The following table gives a list of the more prominent among the after-shocks, which occasioned more or less damage.

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* F. Omori : "on the Earthquakes in Formosa." *Reports* (Japanese) *of the Imperial Earthquake Investigation Committee*, No. 54.

No.	Date. 1906.	Time of occurrence at the origin.*	Prefecture.	Number of Killed.	Number of Wounded.	Number of Houses totally destroyed.	Number of Houses partially destroyed.
Initial Eq.	March 17	6. 42. 30 A.M.	Toroku.	11	35	254	293
			Kagi.	1237	2338	5345	2900
			Ensuikō.	1	5	68	40
1	March 26	11. 29. 20 A.M.	Toroku.	0	4	16	17
			Kagi.	1	1	4	26
2	April 4	8. 42. 00 P.M.	Kagi.	0	0	5	--
3 4 5	April 6 „ 7 „ 8	2. 58. 00 A.M. 0. 52. 40 P.M. 6. 39. 40 A.M.	Kagi.	0	4	39	59
			Ensuikō.	1	2	13	35
6 7	April 14 „ „	3. 18. 00 A.M. 7. 52 00 „	Kagi.	9	56	829	1320
			Toroku.	1	4	34	55
			Ensuikō.	3	17	659	482
			Tainan.	0	[illegible]	6	25
			Banshoryō.	2	4	4	15
			Hōzan.	0	2	2	7
			Shōka.	0	1	5	1
			Taichu.	0	0	1	1

It may here be noted that the study of the after-shocks of the Mino-Owari and other recent large Japan earthquakes has shown the existence of a series of periods in the variation of the number and intensity of these shocks, the most well-defined ones being 4½ days, 8 or 9 days, about 12 days, and about 33 days, in length.

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* Times are given in that of longitude 120° E.

Of these, the first is evidently the fundamental period, and the others are probably its multiples.* I have recently examined the variation from day to day of the atmospheric pressure for Tokyo, Gifu, and for whole Japan, and found the periods of 4.6 days, 9.0 days, and 34 days. It thus seems highly probable that the different periods in the seismic frequency above mentioned are due to the fluctuations in the barometric pressure.†

Now what is very interesting of the after-shocks of the Formosa earthquake of March 17, 1906, is the regularity with which strong shocks happened successively, the period being that of 9 days. Thus the first strong after-shock (No. 1 in the foregoing table) took place on March 26, about 9 days 5 hours after the initial violent earthquake. As this circumstance seemed to indicate the predominance of the 9-days periodicity, I predicted the possible repetitions of strong after-shocks at this interval. This was practically verified, and the next severe shock (No. 2) occurred on April 4, about 9 days 9 hours after the first (No. 1), the strong shocks Nos. 3, 4, and 5 being regarded as forming a group with No. 2. Thus the inhabitants in the city of Kagi and other places began to put great faith in the periodicity of the recurrence of seismic phenomena, such that on the night of April 13, which happened to be 9 days after April 4, the date of the shock No. 2, many people anticipated the occurrence of a strong disturbance and did not go to sleep. As a matter of fact there took place the next morning two very severe earthquakes, the time interval in this case being 9 days 7 hours.

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* F. Omori: "The After-shocks of Earthquakes." Jour. Coll. Sc., Imp. Univ. Tokyo, Vol. VII, Part 2.

† F. Omori: "On long-periods Variations of the Atmospheric Pressure" *Reports* (Japanese). *of the Imp. Earthquake Investigation Committee, No. 57.*

The earthquake No. 7, which was the strongest among the aftershocks, apparently restored the equilibrium of the disturbed earth's crust in this part of Formosa, there being no subsequent severe shock.

Tokyo.

January 1907.

Comparison of the Faults in the Three Earthquakes of Mino-Owari, Formosa, and San Francisco.

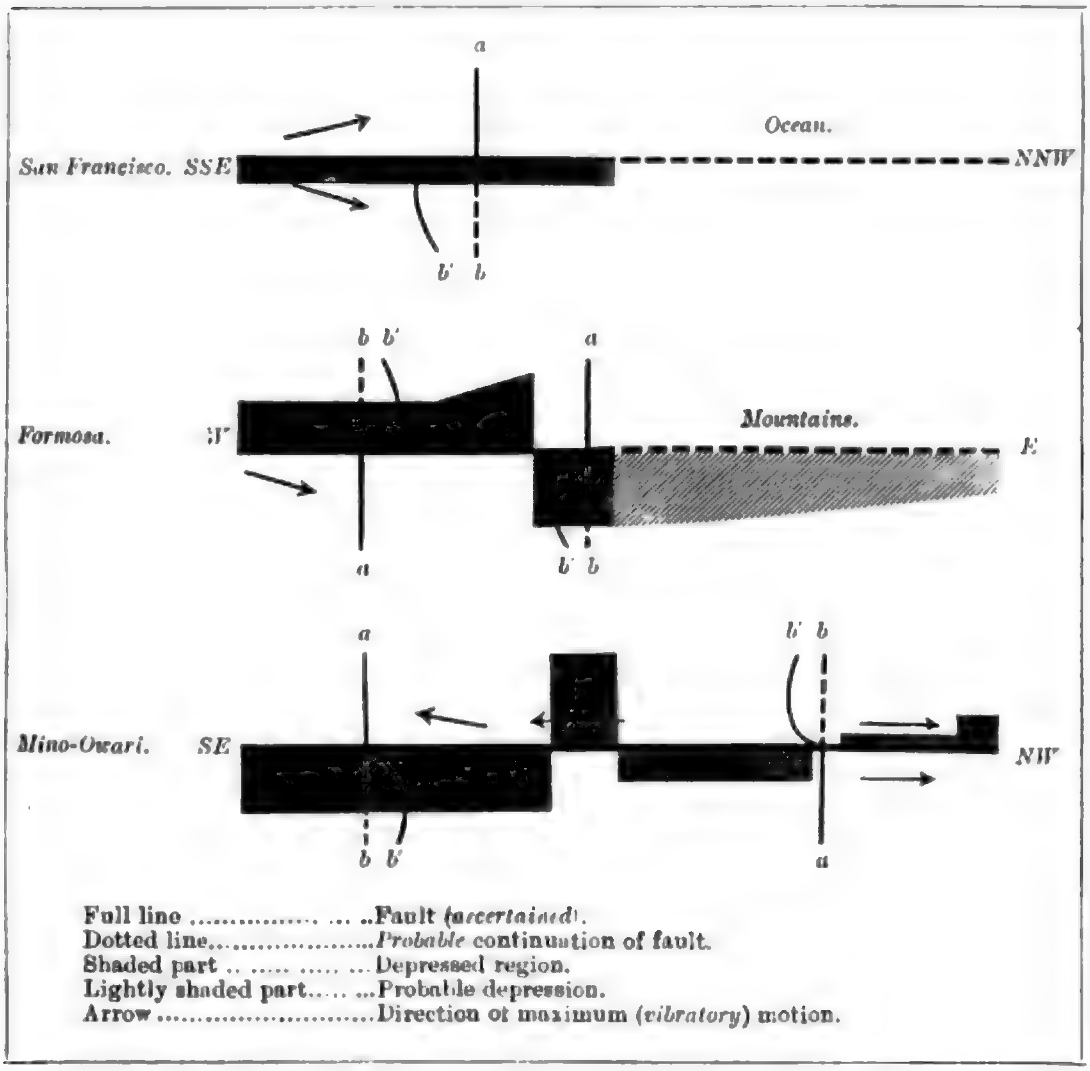
By

F. Omori, Sc. D.,
Member of the Imperial Earthquake Investigation Committee.

The three great earthquakes of Mino-Owari (Central Japan) on Oct. 28, 1891, of Kagi (Formosa) on March 17, 1906, and of San Francisco on April 18, 1906, were each accompanied by the formation of remarkable *faults*, whose total lengths were about 100, 50, and 430^{km} respectively. The dislocation in the San Francisco earthquake was formed partly along, and partly off, the west coast of California, belonging to the category of longitudinal faults. The dislocations in the Mino-Owari and Kagi earthquakes were, on the other hand, formed nearly at right angles to the course of the Main Island (Nippon) and the axis of Formosa Island respectively, both belonging to the category of transverse faults. Notwithstanding these differences, there are certain similarity among the three cases. Thus, in each earthquake, the direction of motion at different places in the immediate neighbourhood of the fault was not perpendicular, but more nearly parallel, to the latter. This seems to indicate that the formation of the faults was mainly due, in each case, not to such actions as the simple falling down or sudden creation of a cavity underground, but to the existence of shearing stresses in the plane of fracture, possibly of two opposing forces acting either from the centre toward both ends of the fault line, or toward the centre from both ends.

The accompanying figure is a diagrammatic illustration of the 3 faults, the line *ab* indicating, in each case, a straight line (say, road) which suffered a shearing movement in such a way that the part *b* on the depressed side was displaced to the new position *b′*, being generally transformed into a curve.

From the figure it will be seen that there existed in each fault what may be called the central point, where the disturbance of the ground is greatest and about which the shear and depression along the line of dislocation is more or less symmetrical.



Full line ....Fault (*ascertained*).
Dotted line......................*Probable* continuation of fault.
Shaded part .. .. Depressed region.
Lightly shaded part..... ...Probable depression.
Arrow ....Direction of maximum (*vibratory*) motion.

In the case of the Mino-Owari earthquake the central point was in the vicinity of the village of Midori in the Neo-Valley, where a very remarkable depression of the ground took place. The corresponding point on the Formosa fault was between the villages of Bisho and Kaigenkō. In the San Francisco earthquake the northern half of the fault was under the ocean, but the central point was probably in the vicinity of the Tomales Bay, the greatest amount of disturbance having occurred there.

The greatest vertical dislocation of 18 feet occurred in the Mino-Owari earthquake, while the greatest horizontal shear occurred in the San Francisco earthquake. The latter has shown a vertical displacement of only 1 or 2 feet, while the former was accompanied by a large horizontal shear of about 18 feet. In the Formosa earthquake, whose magnitude was much smaller than the other two, the vertical and the horizontal displacements of the ground were each of a moderate scale, the maximum amounts being 6 and 8 feet respectively.

The maximum vibratory motion in the Mino-Owari earthquake showed a tendency of being directed from the central point towards both ends; while, in each of the two other earthquakes, the same motion was, as far as can be ascertained, directed from one end towards the centre. Again, the direction of the maximum (vibratory) motion was, in the Formosa earthquake, the same as that of the shear of the depressed ground. In the two other earthquakes, however, the reverse was the case. These differences are probably due to the diversity in the manner of the action of the force along the fault plane which finally produced the dislocations.

Note on the Transit Velocity of the Formosa Earthquakes of April 14, 1906.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. The time of occurrence of the severe Formosa earthquake in the morning of April 14, 1906,* has been exactly observed by the present writer with a chronometer watch, at Taichu whose epicentral distance is about 90^{km}. The earthquake was also satisfactorily registered by the Omori Horizontal Pendulums at Tokyo, whose epicentral distance is 1710^{km} or $15.^\circ4$. The times‡ of occurrence at these two places were as follows:—

Tokyo	$8^h\ 56^m\ 46^s$ A.M.
Taichu	$8\ \ 52\ \ 22$,,
Difference	$4^m\ 24^s$

As the difference of the epicentral distances of the two places is 1620^{km}, we obtain a mean transit velocity of 6.15^{km} per sec.

2. The above earthquake was preceded by another shock of nearly an equal extension, whose time of occurrence observed at the Meteorological Observatory of Taichu was, with proper time corrections, $4^h\ 18^m\ 20^s$ A.M. The time of the same earthquake registered by the seismographs at Tokyo was $4^h\ 22^m\ 20^s$ A.M.‡ From these observations we obtain:—

Time difference between Tokyo and Taichu $= 4^m\ 0^s$.
Mean velocity ,, ,, ,, ,, $= 6.75^{km}$ per sec.

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* See page 66.

‡ These times are given in that of longitude 135° E.

3. Supposing the value of the transit velocity given in § 1 to be twice as accurate as that given in § 2, and taking the mean, we obtain :--

$$\text{velocity} = 6.35^{km} \text{ per sec.}$$

This value which relates to the distance difference between the epicentral arcual length of $0.^\circ 8$ and $15.^\circ 4$, although it is the result of calculation by the *difference method*, is really that calculated by the *direct method*, as one of the places taken for comparison, namely, Taichu, was quite near the earthquake origin.

Notes on the Valparaiso and Aleutian Earthquakes of Aug. 17, 1906.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. *Introduction.* It is a quite remarkable fact that, on Aug. 17, 1906, almost simultaneously with the great Valparaiso earthquake there was another large shock off the Aleutian Islands. As will be seen from later §§, the Valparaiso shock occurred at 0^h 40^m 05^s (G.M.T.), the approximate position of the origin being $\varphi = 31°$ S, $\lambda = 73°$ W. The other earthquake took place 28^m 21^s earlier, or at 0^h 11^m 44^s (G.M.T.), the origin being approximately at $\varphi = 50°$ N, $\lambda = 175°$ E. As will be seen from Fig. 1, the latter position is on the outer side of the Aleutian Islands arc, where the sea bottom quickly descends to the north Pacific basin whose depth is over 7000 metres. The topography of the vicinity of the origin of the Valparaiso earthquake is also highly characteristic, there being a marked contrast between the depth of the water and the elevation of the mountains. Thus, there is, quite close to the coast, the Chile basin, where the water depth is over 7600 metres, (Fig. 2), while the peak of Aconcagua, in the Andes, reaches an elevation of 6970 metres.

The Aleutian earthquake furnishes an instance of the seismic manifestation along the exterior, or convex, side of an arc formed by a series of islands or mountain chains, such side being generally much steeper than the inner, or concave, side. The Japanese Islands, the Himalayan mountains and the two islands of Java and

Sumatra are other good examples of the relation of the seismic activity to the curvilinear topographical form.[*]

2. *Relation between the Valparaiso and Aleutian Earthquakes.* The centres of the two earthquakes of Valparaiso and Aleutian Islands are separated by an arcual distance of 126° 56′, or by a little more than two-thirds of the earth's semi-circumference. The interesting feature is that these two disturbances were no independent phenomena, but were simultaneous manifestations of seismic energy at both ends of the great earthquake zone extending along the whole Pacific coast of North and South America. The latter zone is indicated, in Fig. 3,[‡] by a line marked 5......6, the numerals 1, 2, 3 and 4, indicating the approximate positions of the different previous earthquakes, as follows :—

(1)............Alaska Earthquakes of 1899 and 1900.
(2)............Mexico and Central America earthquakes of 1900 and 1902.
(3)............Panama, Columbia and Equador earthquake of 1906.
(4)............San Francisco earthquake of 1906.

5 and 6 indicate respectively the origins of the Aleutian and Valparaiso earthquakes. The position of the centre of the first of the last mentioned disturbances is near to the Kuriles and Hokkaido and may be regarded as the approach to the north-eastern part of Japan of the great seismic activity already manifested along the other side of the Pacific. The successive occurrence of large destructive earthquakes along the zone extending from the north

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[*] These relations have been discussed in detail by the present Author in the *Reports* (Japanese) *of the Imp. Earthquake Inv. Com., No.* 49. See also the next Article.

Figs. 1 and 2 are based on "Stiller Ozean" edited by Seewarte (Hamburg).

[‡] This is a slight modification of Fig. 20, given on page 22, of the *Bulletin*, No. 1.

Mediterranean to the Himalayas, and possibly to Formosa, has already been noted in the *Bulletin*, No. 1.*

3. *Seismograms.* As stated before, the Aleutian earthquake occurred nearly half an hour before the Valparaiso earthquake. The motion due to the latter disturbance was, therefore, in the seismographic records partly confused by that due to the former. In the seismograms obtained at the different Japanese stations, however, this circumstance caused no mistake, as the commencement of the Valparaiso earthquake was clearly indicated by the appearance of small quick vibrations usually marking the 1st preliminary tremor of the seismic motion. The Vicentini seismogram obtained at Manila also shows clearly the vibrations due to the Chilian earthquake.

I have here to express my thanks to the Directors of the Observatories of Osaka, Manila, Ximeniano, Quercc, and other places, who have kindly supplied me with the copies of the seismograms relating to the two earthquakes in question.

Most of the observers in Europe have, in the analysis of the seismograms, mistaken the first or Aleutian Earthquake for that of Valparaiso, the only exceptions as far as I know being Padre Alfani and Professor Wiechert. Padre Alfani has written a note on the results obtained at the Ximeniano observatory, giving 0^h 58^m 15^s (G.M.T.) for the commencement of the 2nd (Valparaiso) earthquake.‡ Professor Wiechert gives 1^h 13^m 30^s (G.M.T.) for the corresponding phase of motion observed at Göttingen.

I give next the result of the analysis of the seismograms obtained at Tokyo, Osaka, Manila, and Quercc. As usual, the symbols a, $2a$, and T, will be used to denote respectively the amplitude, double amplitude, and the complete period of vibration. *The times are always given in G.M.T.*

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* See also next Article.

‡ Padre Alfani: "Appunti sul Terremoto di Valparaiso." *Rivista di Fisica, Matematica e Scienze Naturali* (Pavia), No. 82. 1906.

ANALYSIS OF THE SEISMOGRAMS.

4. *Observation at Hongo, Tokyo.*

(i) EW Component. Fig. 5, Pl. XXIV.

Pl. XXIV is a reproduction of the EW Component diagram given by a horizontal pendulum set up in the brick "earthquake-proof house," at Hongo, the instrumental constants being as follows*

Period (complete) of free oscillation=28 sec.

Multiplication of the pointer=10 times.

Weight of the heavy cylinder=14 kg.

Length of the horizontal strut, or the distance between the centre of the heavy cylinder and the point of support=1 metre.

Vertical distance between the points of support and of suspension=2.5 metres.

Aleutian Earthquake. Commencement=$0^h\ 17^m\ 20^s$.

Preliminary Tremor. Duration=$5^m\ 23^s$. During the first $1^m\ 5^s$, the motion was very small, the commencement being slightly uncertain :— T=6.4 sec.

For the next $1^m\ 55^s$, the motion was well defined, forming the most active part in this phase :—

T=8.5 sec., $2a$=0.35 mm.

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[*] This is one of the horizontal pendulums constructed in 1897, which has been referred to as A-apparatus in the *Publications*, No. 5.

The subsequent motion was smaller, consisting of the three following sets of vibrations :—

$$\begin{cases} T=\ 9.0 \text{ sec.,} & 2a=0.27 \text{ mm.} \\ T=\ 4.3 \ \ ,, & \text{(small).} \\ T=30.9 \ \ ,, & 2a=0.35. \end{cases}$$

Principal Portion. Commencement$=0^h 2$[illegible]$^m\ 43^s$. [1st & 2nd phases.] Duration$=2^m\ 05^s$. The very first displacement was $a=$ 1.4 mm., directed towards W. The motion was as follows :—

During the 1st 50 sec .... $T=25.0$ s., $2a=2.9$ mm.

,, next $1^m\ 15^s$...... $\begin{cases} T=37.5 \text{ s.,} & 2a=2.0 \text{ mm.} \\ T=\ 8.0 \text{ s.,} & \text{———} \end{cases}$

[3rd phase]. Duration$=2^m\ 56^s$. The record consists entirely of nearly equal pendulum oscillations as follows :—

$T=27.1$ sec., max. $2a=9.8$ mm. (2nd vibration).

The very first displacement in this phase was $a=4.5$ mm., directed towards W.

[4th phase]. Duration$=3^m\ 2^s$:—

$T=20.2$ sec., $2a=5.6$ mm.

The subsequent motion was as follows :—

(i) During the 1st $10^m\ 00^s$:—

$$\begin{cases} T=19.4 \text{ sec.,} & 2a=1.78 \text{ mm.} \\ T=11.1 \ \ ,, & \ \ ,, =1.20 \ \ ,, \end{cases}$$

(ii) During the next $10^m\ 55^s$:—

$$\begin{cases} T=17.0 \text{ sec.,} & 2a=1.20 \text{ mm.} \\ T=10.5 \ \ ,, & \ \ ,, =1.00 \ \ ,, \\ T=34.5 \ \ ,, & \text{———} \end{cases}$$

(iii) During the next $9^m\ 16^s$:—

$$\begin{cases} T=10.5 \text{ sec.,} & 2a=0.55 \text{ mm.} \\ T=18.7 \text{ ,,} & \text{,,}=0.55 \text{ ,,} \\ T=\ \ 8.3 \text{ ,,} & \text{(small).} \end{cases}$$

Then there appeared the commencement of the 2nd or Valparaiso earthquake.

Valparaiso Earthquake Commencement $=1^h\ 00^m\ 55^s$.

1st *Preliminary Tremor.* Duration $=18^m\ 58^s$. The commencement of the Valparaiso earthquake was marked by the appearance of small quick movements of T=about 4 sec., mixed with the vibrations constituting the end portion of the Aleutian earthquake. $7^m\ 45^s$ later on there appeared again some small movements, of similar sort which were probably the seismic motion propagated along the major arc between Chile and Tokyo. The elements of motion in this phase, which partly relates to the vibrations belonging to the Aleutian earthquake, were as follows :—

$$\begin{cases} T=\ \ 9.3 \text{ sec.,} & 2a=0.53 \text{ mm.} \\ T=14.5 \text{ ,,} & \text{,,}=0.5 \text{ ,,} \\ T=29.7 \text{ ,,} & \text{------} \end{cases}$$

The end of the 1st preliminary tremor was not well defined.

2nd *Preliminary Tremor.* Commencement $=1^h\ 19^m\ 53^s$. Duration $=23^m\ 36^s$. During the first $6^m\ 3^s$, the motion was comparatively small. During the next $3^m\ 15^s$, there were 6 regular vibrations :—

$$T=32.5 \text{ sec.,} \qquad 2a=0.85 \text{ mm};$$

mixed with small movements of $T=9.3$ sec.

The subsequent motion was as follows :—

(i) During $2^m\ 48^s$, the motion was small :—

$$\begin{cases} T=\ \ 9.7 \text{ sec.,} & 2a=0.32 \text{ mm.} \\ T=18.9 \text{ ,,} & \text{,,}=0.3 \text{ ,,} \end{cases}$$

(ii) During 59^s, there were 2 slow vibrations :—

$T=29.5$ sec., $2a=0.6$ mm.

(iii) During $5^m\ 47^s$, motion was small :—

$$\begin{cases} T=11.8 \text{ sec}, & 2a=0.3 \text{ mm.} \\ T=\ 8.7 \ ,, & ,, =0.2 \ ,, \end{cases}$$

Then, at $1^h\ 38^m\ 31^s$, the motion became again somewhat more active, possibly corresponding to the propagation along the major arc. The motion during the remaining $4^m\ 43^s$ was as follows :-

$$\begin{cases} T=11.2 \text{ sec.}, & 2a=0.42 \text{ mm.} \\ T=\ 8.2 \ ,, & \text{———} \end{cases}$$

The end of the 2nd preliminary tremor was not well defined.

Principal Portion. Commencement $=1^h\ 43^m\ 13^s$.

(i) During the 1st $8^m\ 32^s$:

$$\begin{cases} T=\ 9.2 \text{ sec}, & 2a=0.25 \text{ mm.} \\ T=12.5 \ ,, & 2a=0.25 \ ,, \\ T=37.7 \ ,, \ (?) & \end{cases}$$

(ii) During the next $2^m\ 14^s$:—

$T=32.8$ sec., $2a=0.6$ mm.

This part which probably corresponds to the 3rd phase of the principal portion, occurred at $1^h\ 51^m\ 45^s$.

(iii) During the next $8^m\ 33^s$, there were 2 max. groups :—

$$\begin{cases} \text{1st group} \ldots \ldots \text{Duration}=3^m\ 46^s; & T=22.6 \text{ sec.}, & 2a=2.35 \text{ mm.} \\ \text{2nd} \ ,, \ \ldots \ldots \text{Duration}=3^m\ 58^s; & T=21.6 \ ,, , & 2a=2.0 \ ,, . \end{cases}$$

In the minimum part between these two maxima, there were small vibrations of $T=19.3$ sec.

(iv) During the next $11^m\ 40^s$:—

$T=18.3$ sec, $2a=0.74$ mm.

At minimum epochs there were small vibrations of $T=8.8$ sec.

(v) During the next $22^m\ 15^s$:—

$T=19.0$ sec., $2a=0.5$ mm.

Then at $2^h\ 36^m\ 59^s$, there took place two well defined vibrations :—

$T=20.0$ sec., $2a=0.75$ mm.

These may correspond to the 3rd phase of the principal portion propagated along the major arc. For the next $4^m\ 14^s$:—

$T=22.1$ sec.

Thereafter the motion consisted of quick vibrations and gradually died away, with alternations of maximum and minimum groups. The motion during the subsequent successive epochs was as follows.

(i) During $6^m\ 34^s$:—

$T=16.4$ sec., $2a=0.26$ mm.

(ii) During $6^m\ 57^s$:—

$T=18.2$ sec., $2a=0.29$ mm.

(iii) During $5^m\ 10^s$:—

$T=17.2$ sec., $2a=0.1$ mm.

(iv) During $9^m\ 14^s$:—

$T=15.8$ sec., $2a$ (small).

At $3^h\ 52^m\ 21^s$ there appeared again some slight slow vibrations of $T=18.3$ sec., which were probably due to the Aleutian earthquake, being the W_3 motion, or the repetition of the motion (3rd phase of the principal portion) first propagated along the minor arc.

(ii) Vertical Component. Fig. 6, Pl. XXIV.

Fig. 6, Pl. XXIV is a reproduction of the diagram given by a vertical motion seismograph, whose instrumental constants have been given in the *Bulletin*, No. 1, being as follows :—

Length of the vertical spiral springs=1.2 metre.

Horizontal distance between the centre of the steady mass and the pivot =1.2 metre.

Weight of the heavy bob=9 kg.

Natural oscillation period=6.0 sec.

Multiplication of the pointer=12.

Aleutian Earthquake. Commencement=$0^h\ 17^m\ 11^s$.

Preliminary Tremor. Duration=$5^m\ 33^s$. The motion began with quick movements, the vibrations during the successive epochs being as follows.

(i) $1^m\ 5^s$………$T=3.3$ sec., $2a=0.05$ mm.

(ii) $2^m\ 20^s$ ……Motion was active :—

$$\begin{cases} T=9.4 \text{ sec.,} & 2a=0.09 \text{ mm.} \\ T=5.2 \text{ ,,} & \text{,,} =0.15 \text{ ,,} \\ T=3.6 \text{ ,,} & \text{(small).} \end{cases}$$

(iii) $2^m\ 8^s$………Motion was small and nearly uniform :—

$T=3.5$ sec., $2a=0.03$ mm.

Principal Portion. Commencement=$0^h\ 22^m\ 44^s$.

For the first $2^m\ 40^s$, the motion was small, but there were traces of some slow vibrations :—

$$\begin{cases} T=22.8 \text{ sec.,} & \text{———} \\ T=\ 4.7 \text{ ,,} & 2a=0.09 \text{ mm.} \end{cases}$$

Then set in the slow vibration epoch, the motion being most marked for the next $6^m\ 30^s$, as follows :—

(i) $1^m\ 8^s$.........There were 2 slow movements :—

$\begin{cases} T=34.0 \text{ sec.}, & 2a=0.19 \text{ mm.} \\ T=\ 4.0 \text{ ,,} & \text{(small).} \end{cases}$

(ii) $1^m\ 11^s$.........There were 3 well defined vibrations :—

$T=23.7$ sec., $2a=0.22$ mm.

(iii) $4^m\ 8^s$.........The amplitude gradually decreased :—

$\begin{cases} T=20.7 \text{ sec.}, & 2a=0.17 \text{ mm.} \\ \text{T}=12.4 \text{ ,,} & \text{———} \end{cases}$

The subsequent motion was small and regular, the vibrations during the successive epochs being as follows :—

(i) $5^m\ 5^s$ .... $T=21.8$ sec., $T=10.9$ sec.
(ii) 2 9 ....$T=16.1$,,
(iii) 1 50 ....$T=11.0$,,
(iv) 3 39 ....$T=16.9$,,
(v) 9 54 ....$T=11.7$,,

Valparaiso Earthquake. Commencement$=1^h\ 00^m\ 34^s$.

1*st Preliminary Tremor.* Duration = about 18^m. The commencement of the Valparaiso earthquake was indicated by the appearance of small quick vibrations :—

$T=3.5$ sec., $2a=0.12$ mm.

These vibrations existed more or less throughout this phase of motion. There were, however, some increase in amplitude at $6^m\ 35^s$ after the commencement of the earthquake, due probably to the propagation along the major arc.

2*nd Preliminary Tremor.* The motion now consisted entirely of slow vibrations, as follows :—

(i) During the first $7^m\ 16^s$: $T=11.1$ sec.
(ii) ,, ,, next $7^m\ 28^s$: $T=11.2$ sec.

3rd Phase of the Principal Portion. Commencement$=1^h\,52^m\,18^s$. The motion began with slow vibrations of $T=26.8$ sec., which were comparatively small during the first $3^m\,7^s$. During the next $9^m\,25^s$, the motion was most active :—

(i) For the 1st $3^m\,44^s$:—$T=22.4$ sec., $2a=0.046$ mm.
(ii) „ „ next $5^m\,41^s$:—$T=19.2$ „ $2a=0.05$ mm.

The subsequent motion was smaller, the T being$=17.1$ sec.

(iii) EW Component. Fig. 7, Pl. XXV.

Fig. 7, Pl. XXV gives the earlier part of the EW component of the Aleutian earthquake as recorded by a duplex horizontal pendulum apparatus* in the Seismological Institute, whose instrumental constants are as follows :—

Period of free oscillation$=41.5$ sec.
Multiplication of the pointer$=30$ times.
Weight of the heavy cylinder$=16.5$ kgm.
Length of the horizontal strut$=0.75$ metre.
Vertical distance between the points of support and of suspension $=1$ metre.

Aleutian Earthquake.

Preliminary Tremor. Duration$=5^m\,5^s$. The very 1st displacement was well marked, being $a=0.04$ mm., directed toward W. For the next $1^m\,3^s$, the motion was small :—

$T=5.0$ sec., $2a=0.05$ mm.

Then the motion became suddenly large, commencing with a displacement of $a=0.25$ mm., toward W, followed by the counter motion of $2a=0.43$ mm. toward E. During the next $4^m\,2^s$, T was 8.3 sec.

---

* This is a portable form instrument described in the *Publications*, No. 18.

Pricipal Portion. The motion became much larger, the 4 initial displacements being as follows :—

(i) $a=0.25$ mm., toward W.
(ii) $2a=0.78$ „ „ E.
(iii) $2a=1.72$ „ „ W.
(iv) $2a=2.57$ „ „ E.

Then the pointer went out of the smoked paper, toward W. The period of these vibrations was 31.2 sec., there being also some small movements of $T=9.3$ sec.

Later on the pointer again entered on the smoked paper, recording the end portion due to the Chilian earthquake :—

$T=16.4$ sec.

(iv) **NS Component.** Fig. 8, Pl. XXV.

The record was taken by a long period horizontal pendulum set up in the "earthquake-proof house," whose instrumental constants are as follows :—

Vertical distance between the points of suspension and of support =2 metres.
Effective length of the strut, or the horizontal distance between the point of support and the steady axis=1 metre.
Weight of the heavy bob=46 kgm.
Natural oscillation period=48.5.
Multiplication of the pointer=20.

Aleutian Earthquake.

Preliminary Tremor. Duration=5^m 19^s. The commencement is well defined, the initial displacement being $a=0.06$ mm., toward S. For the first 1^m 1^s, the motion was small :—

$T=$ 5.1 sec., $2a=0.06$ mm.

Fig. 1. Aleutian Islands and the Surrounding Seas.

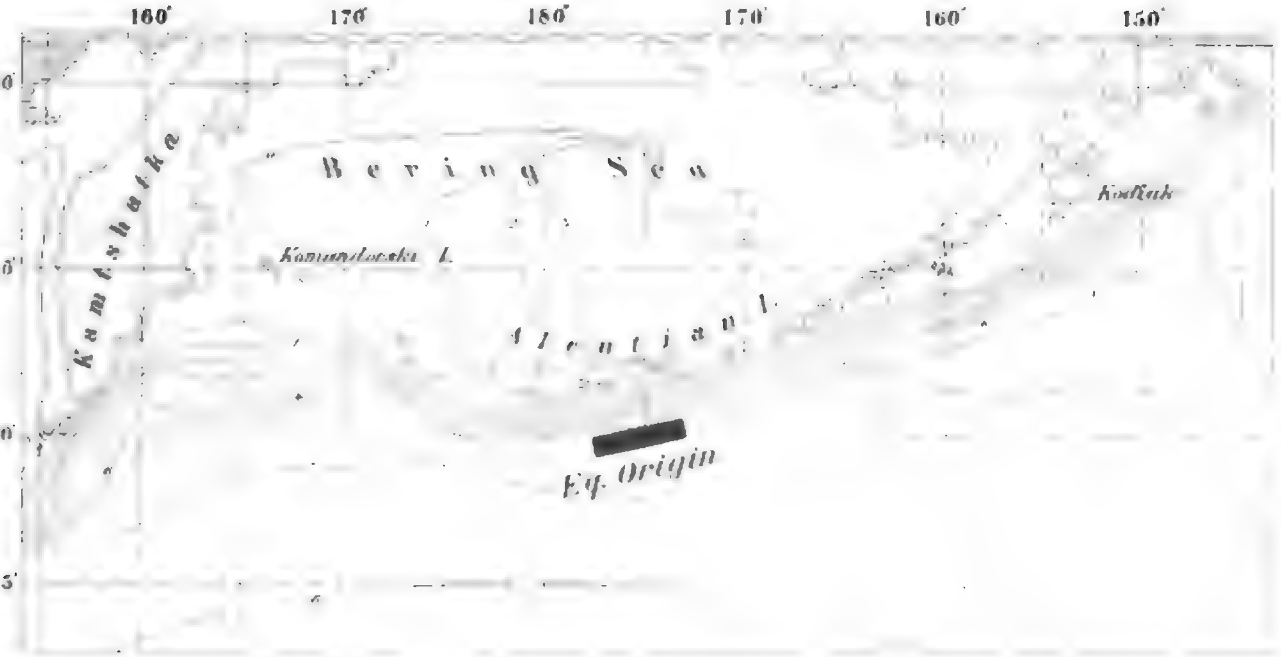

160°
170°
180°
170°
160°
150°
60°
55°
50°
45°
Kamtshatka
Bering Sea
Komandorski I.
Aleutian I.
Kodiak
Eq. Origin

Fig. 2. Showing the Depth of Water off the West Coast of S. America.

In Figs. 1 and 2, the earthquake origins are in each case indicated by a short thick line.

Lines marked 0, 1, 2, ... 7 are the lines of equal depth of 200, 1000, 2000, and 7000 metres respectively

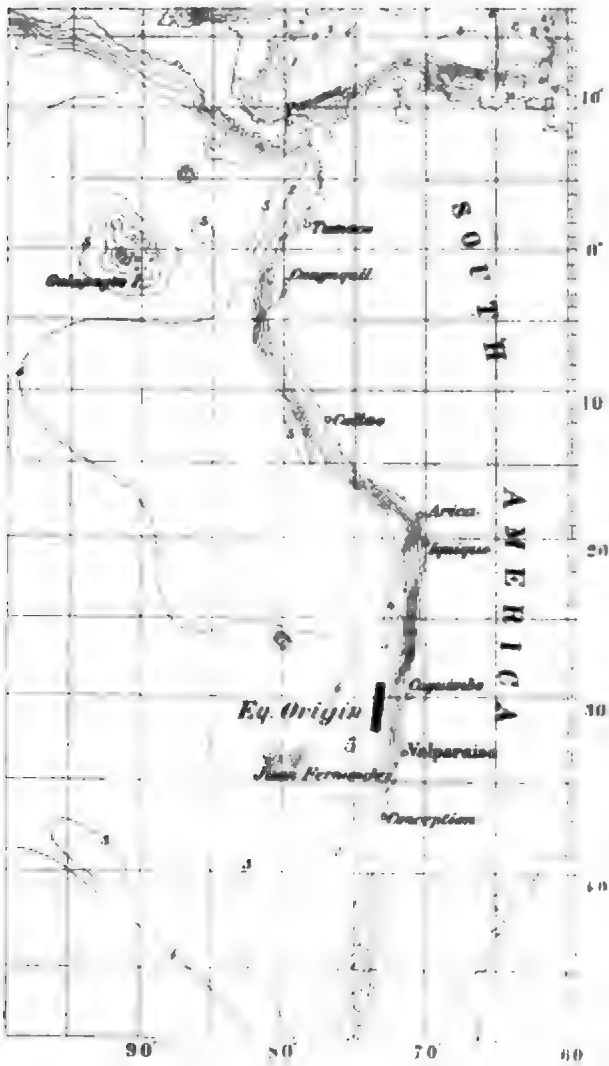
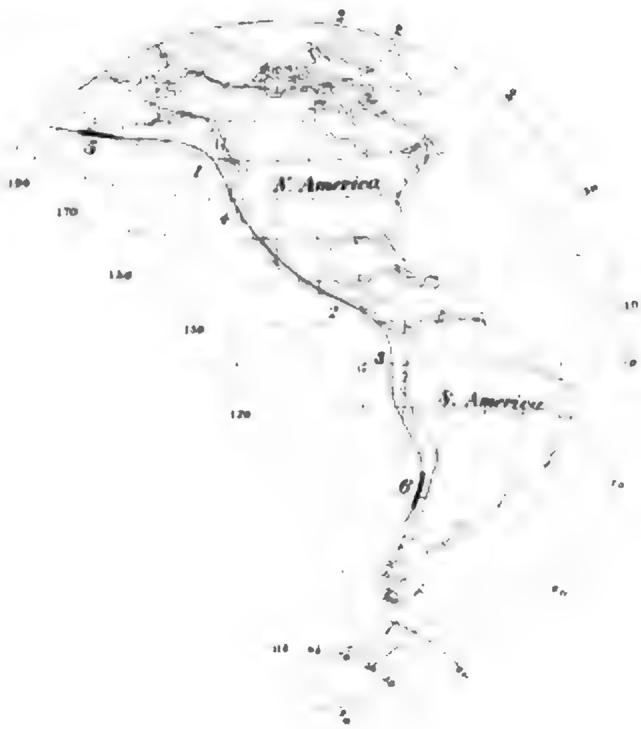

10°
0°
10
20°
30
40
90
80
70
60
SOUTH AMERICA
Tumaco
Guayaquil
Galapagos I.
Callao
Arica
Iquique
Coquimbo
Valparaiso
Juan Fernandez
Concepcion
Eq. Origin
3

Fig. 3. Map showing the Approximate Positions of the different Great Earthquakes which took place along the West Coast of America.


N. America
S. America
3
1
2
3
6
170
150
130
110

n.

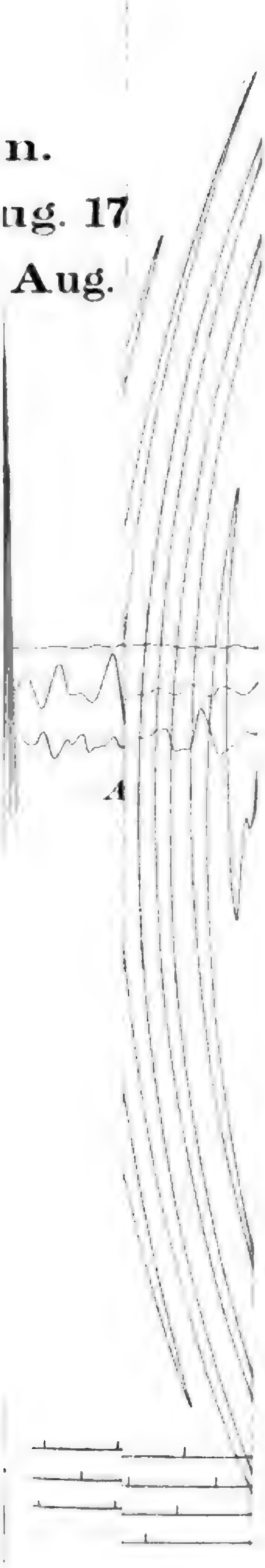
ug. 17

Aug.

n.

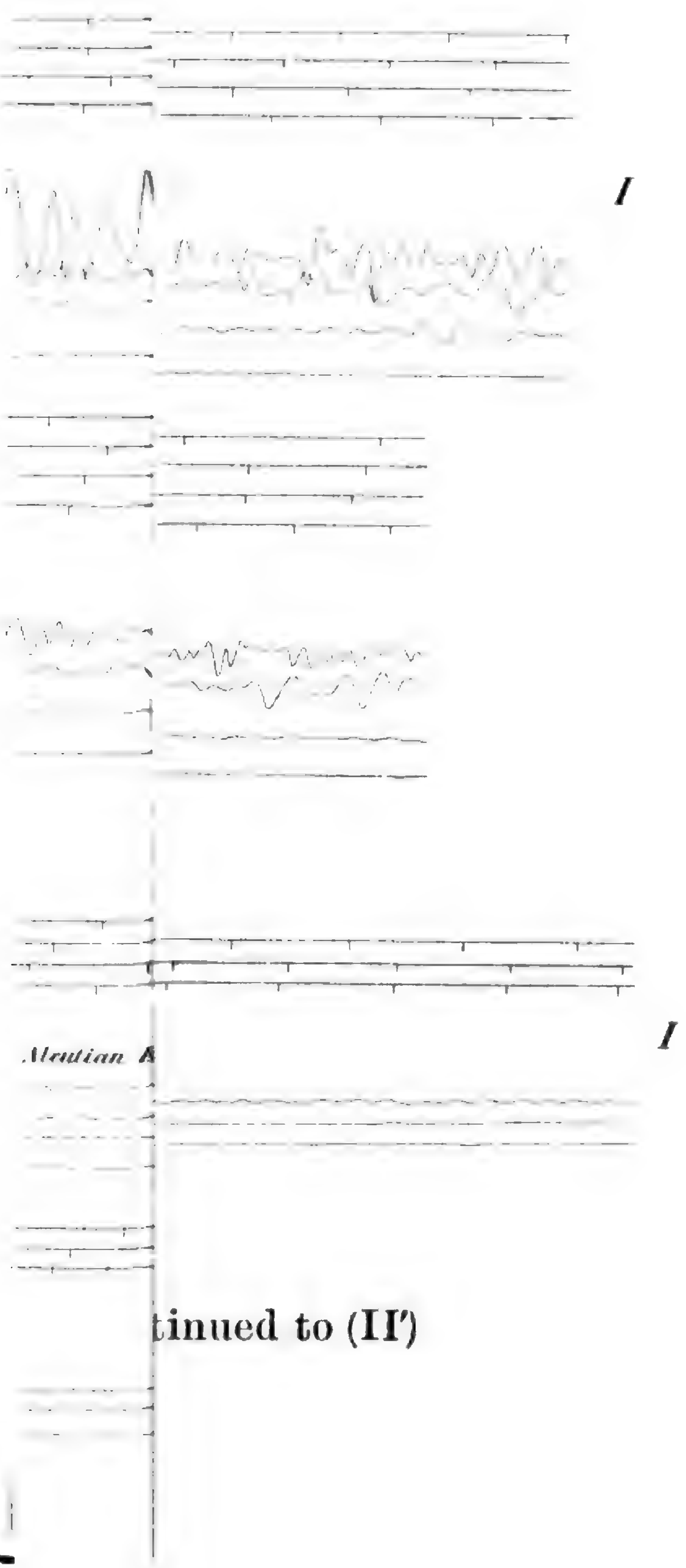
ug. 17

Aug.



PL. XXIV.

and V



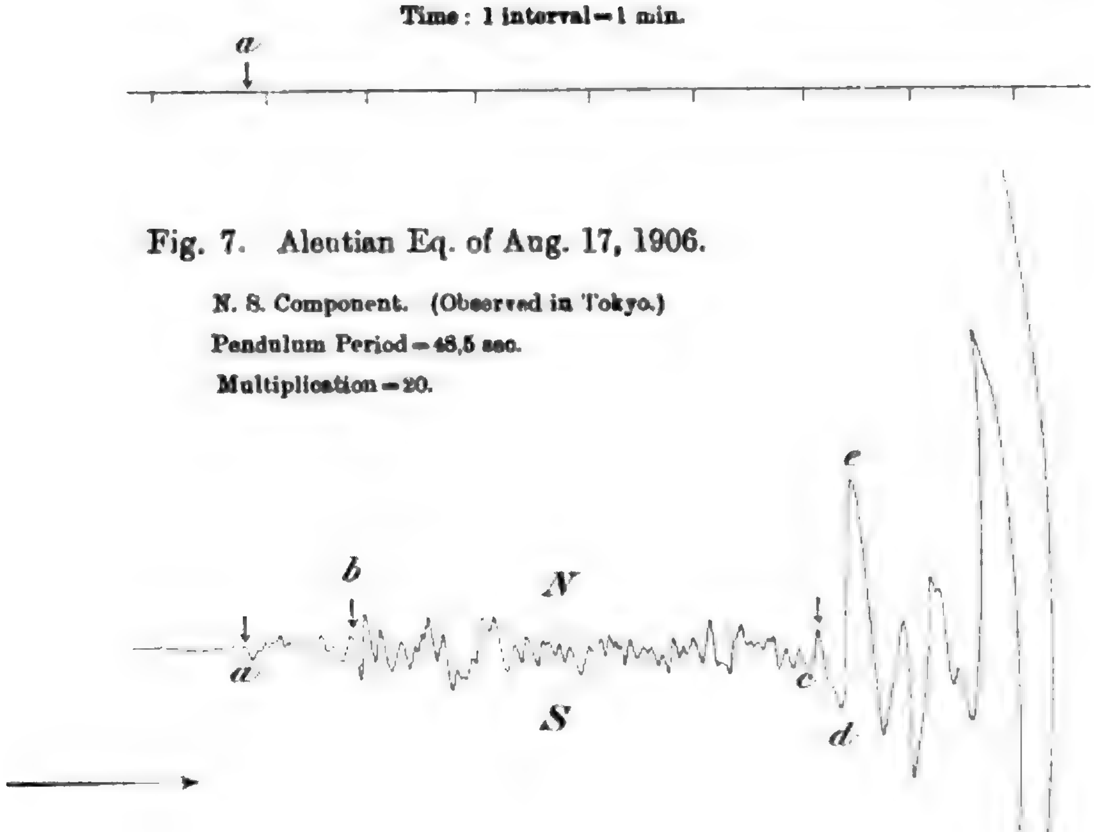


Fig. 7. Aleutian Eq. of Aug. 17, 1906.

N. S. Component. (Observed in Tokyo.)

Pendulum Period = 48,5 sec.

Multiplication = 20.

a.........Commencement.

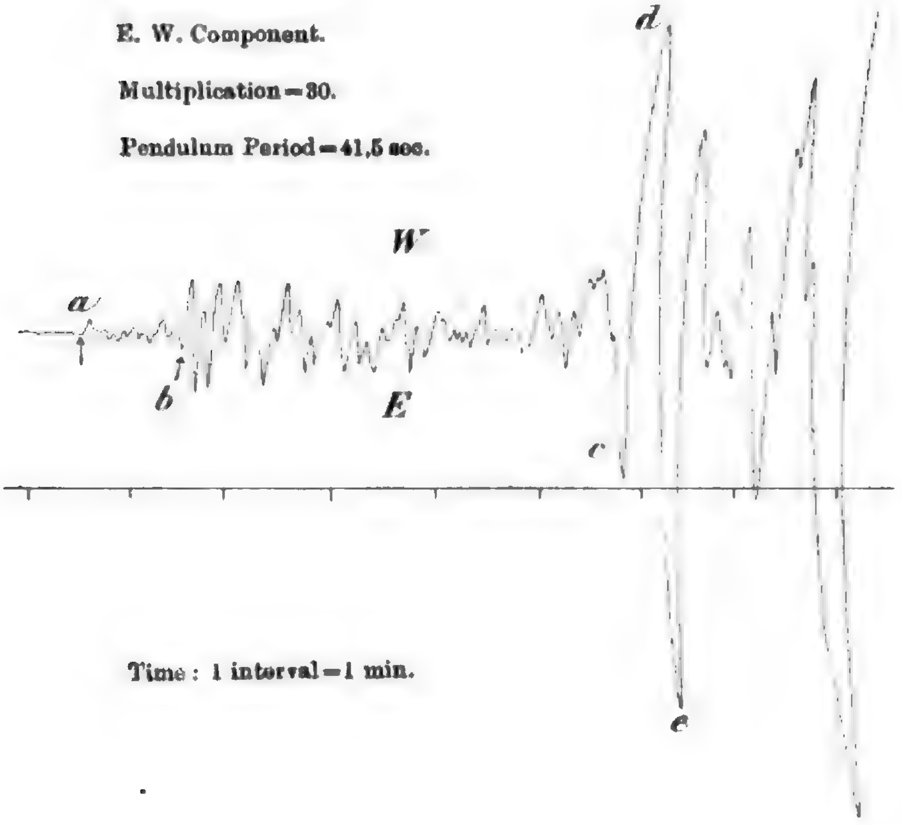
Fig. 8. Aleutian Eq., Aug. 17, 1906.

(Observed in Tokyo.)

E. W. Component.

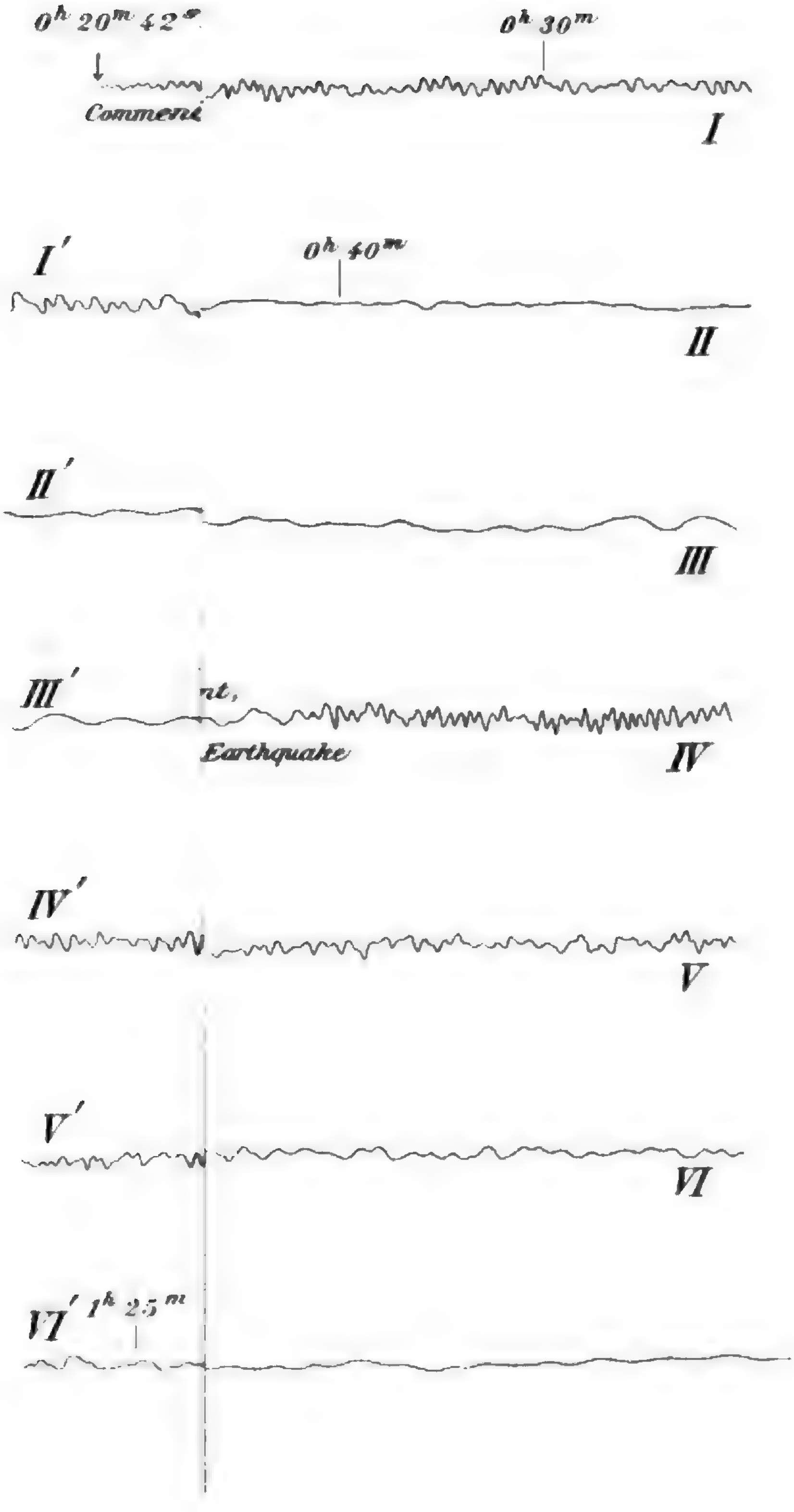
Multiplication = 30.

Pendulum Period = 41,5 sec.



Time : 1 interval = 1 min.

PL. XXVI.



$0^h\ 20^m\ 42^s$
Comment
$0^h\ 30^m$
I
I′
$0^h\ 40^m$
II
II′
III
III′
nt,
Earthquake
IV
IV′
V
V′
VI
VI′
$1^h\ 25^m$

$T=20.3$ sec., $2a=0.14$ mm.

Then the motion became larger, the two first movements being as follows :—

$$\begin{cases}\text{(i)} & a=0.24 \text{ mm, toward S.} \\ \text{(ii)} & 2a=0.38 \text{ ,, ,, N.}\end{cases}$$

The T in the subsequent part was 7.9 sec., there being also some small vibrations of $T=3.9$ sec., $T=18.4$ sec.

Principal Portion. For the first $1^m\ 40^s$, the motion was small comparatively and had a period of $T=30.7$ sec., the three initial displacements being as follows :—

$$\begin{cases}\text{(i)} & a=0.43 \text{ mm, toward S.} \\ \text{(ii)} & 2a=1.3 \text{ ,, ,, N.} \\ \text{(iii)} & 2a=1.4 \text{ ,, ,, S.}\end{cases}$$

At the end of this epoch there took place a vibration consisting of the two following displacements :—

$$\left.\begin{cases}\text{(i)} & a=2.2 \text{ mm, toward N.} \\ \text{(ii)} & 2a=6.35 \text{ ,, ,, S.}\end{cases}\right\}\text{......}T=33.8 \text{ sec.}$$

The next motion was still greater and the pointer went out of the smoked paper, toward N. Later on the pointer again entered on the smoked paper, the vibrations in the end portion of the *Chilian earthquake* being as follows :—

$$\begin{cases}T=19.6 \text{ sec.,} & 2a=0.55 \text{ mm.} \\ T=15.3 \text{ ,,} & 2a=0.20 \text{ ,,} \\ T=10.4 \text{ ,,} & 2a=0.05 \text{ ,,} \\ T=22.9 \text{ ,,} & \text{(small).}\end{cases}$$

5. *Observations at Osaka Meteorological Observatory.*

(i) **EW Component.** Fig. 4, Pl. XXIII.

The record was taken by an Omori Horizontal Pendulum Apparatus of portable form, whose instrumental constants are as follows :—

Vertical distance between the points of suspension and of support =86 cm.

Length of the horizontal strut=44 cm.

Weight of the heavy bob=16 kgm.

Period of the free oscillation=27 sec.

Multiplication of the pointer=20 times.

Aleutian Earthquake. Commencement=$0^h\ 16^m\ 52^s$.

Preliminary Tremor. Duration=$5^m\ 36^s$. The motion began quite sharply, the initial displacement being 0.04 mm, toward W. During the first $1^m\ 0^s$, the motion was small :—

$$T=5.5 \text{ sec.}, \qquad 2a=0.055 \text{ mm.}$$

The subsequent motion consisted of several sets of vibrations, as follows :—

$$\begin{cases} \ T=\ 3.6 \text{ sec.}, & 2a=0.055 \text{ mm.} \\ \ T=\ 9.5 \ ,, & 2a=0.08 \ \ ,, \\ (?)\ T=\ 5.8 \ ,, & 2a=0.13 \ \ ,, \\ (?)\ T=33.8 \ ,, & 2a=0.23 \ \ ,, \end{cases}$$

Principal Portion. The two initial displacements were as follows :—

$$\begin{cases} \text{(i)} \quad a=0.45 \text{ mm, toward E.} \\ \text{(ii)} \quad 2a=1.25 \ ,, \quad ,, \quad \text{W.} \end{cases}$$

During the first $2^m\ 20^s$, the motion was small :—

$$T=27.5 \text{ sec.,} \qquad 2a=3.3 \text{ mm. (Pend. Oscilns ?)}$$

For the next $5^m\ 22^s$, the motion consisted of 11 gradually increasing pendulum oscillations :—

$$T=29.4 \text{ sec.,} \qquad 2a=11.2 \text{ mm. (10th vibration);}$$

The 1st vibration being as follows :—

$$\begin{cases} \text{(i)} & a=1.35 \text{ mm, toward E.} \\ \text{(ii)} & 2a=3.05 \text{ ,, } \quad \text{ ,, } \quad \text{W.} \end{cases}$$

The subsequent motion became suddenly smaller, the vibrations during the successive epochs being as follows :—

$$\text{(i)}\ \ 5^m\ 55^s \ldots\ldots\ldots\ldots \begin{cases} T=19.2 \text{ sec.,} & 2a=2.15 \text{ mm.} \\ T=35 \text{ ,,} & \end{cases}$$

$$\text{(ii)}\ \ 7^m\ 16^s \ldots\ldots\ldots\ldots \begin{cases} T=20.4 \text{ sec.,} & 2a=0.78 \text{ mm.} \\ T=15.0 \text{ ,,} & 2a=1.25 \text{ ,,} \\ T=10.3 \text{ ,,} & 2a=0.48 \text{ ,,} \end{cases}$$

$$\text{(iii)}\ \ 5^m\ 29^s \ldots\ldots\ldots\ldots T=16.1 \text{ sec.,} \qquad 2a=0.53 \text{ mm.}$$

$$\text{(iv)}\ \ 12^m\ 02^s \ldots\ldots\ldots\ldots \begin{cases} T=15.9 \text{ sec.,} & 2a=0.25 \text{ mm.} \\ T=11.9 \text{ ,,} & 2a=0.13 \text{ ,,} \end{cases}$$

Then there appeared the earthquake motion due to the Valparaiso disturbance.

Valparaiso Earthquake. Commencement$=1^h\ 00^m\ 15^s$.

1*st Preliminary Tremor.* Duration$=15^m\ 48^s$. The commencement is well marked by the appearance of small regular vibrations of $T=2.4$ sec., superposed by the following movements :—

$$\begin{cases} & T=13.5 \text{ sec.,} \qquad 2a=0.21 \text{ mm.} \\ (?) & T=\ 6.3 \text{ ,,} \qquad \text{(small).} \end{cases}$$

At $1^h\ 09^m\ 47^s$, or $9^m\ 32^s$ after the commencement of this phase, there was again some slight predominance of quick vibrations, which were probably the major arc propagation, the movements being as follows :—

$$\left\{\begin{array}{ll} T=15.5 \text{ sec.,} & 2a=0.14 \text{ mm.} \\ T=\ \ 3.9 \ \ ,, & \end{array}\right.$$

2nd Preliminary Tremor. Commencement=$1^h\ 16^m\ 03^s$. Duration=$24^m\ 25^s$. During the first $9^m\ 3^s$, the motion was as follows :—

$$\left\{\begin{array}{ll} T=12.0 \text{ sec.,} & 2a=0.13 \text{ mm.} \\ T=\ \ 8.0 \ \ ,, & \ ,, \ =0.09 \ \ ,, \\ T=22.3 \ \ ,, & \ ,, \ =0.22 \ \ ,, \end{array}\right.$$

there being at first traces of 3 slow (doubtful) movements of $T=2^m\ 17^s$. Then the amplitude slightly increased, there being, during the next $3^m\ 5^s$, 5 vibrations :—

$$T=37.0 \text{ sec.,} \qquad 2a=0.33 \text{ mm ;}$$

these were mixed with small vibrations of $T=10.9$ sec. For the next $3^m\ 30^s$, the motion was small :—

$$\left\{\begin{array}{ll} T=12.4 \text{ sec.,} & 2a=0.075 \text{ mm.} \\ T=38.2 \text{ sec.,} & \text{(small).} \end{array}\right.$$

For the next $2^m\ 38^s$ there appeared again 5 large vibrations :—

$$T=31.7 \text{ sec.,} \qquad 2a=0.35 \text{ mm.}$$

During the remaining $6^m\ 28^s$, the motion was smaller :—

$$\left\{\begin{array}{ll} T=27.7 \text{ sec.,} & 2a=0.14 \text{ mm.} \\ T=10.0 \ \ ,, & 2a=0.12 \ \ ,, \\ T=12.4 \ \ ,, & 2a=0.07 \ \ ,, \end{array}\right.$$

Principal Portion. Commencement=$1^h\ 40^m\ 24^s$. [1st and 2nd phases.] Duration=$13^m\ 53^s$. The motion began with 2 slow vibrations :—

$T=55.0$ sec., $2a=0.18$ mm.

The subsequent motion was smaller :—

$$\begin{cases} T=19.1 \text{ sec.,} & 2a=0.09 \text{ mm.} \\ T=10.4 \quad ,, & 2a=0.09 \quad ,, \\ (?)\ T=67.4 \quad ,, & \end{cases}$$

[3rd phase, etc.] Commencement$=1^h\ 54^m\ 21^s$. The motion was most active for the first $7^m\ 8^s$:

$T=23.2$ sec., $2a=1.29$ mm.

The subsequent motion was smaller, the vibrations during the successive epochs being as follows.

(i) For $7^m\ 32^s$:—$\begin{cases} T=18.3 \text{ sec.,} & 2a=0.28 \text{ mm.} \\ (?)\ T=45.0 \quad ,, & \end{cases}$

(ii) For the next $4^m\ 55^s$, there was a maximum group :—

$T=17.4$ sec., $2a=0.54$ mm.

(iii) For the next $7^m\ 55^s$, the motion was nearly uniform :—

$$\begin{cases} T=17.4 \text{ sec.,} & 2a=0.36 \text{ mm.} \\ T=15.9 \quad ,, & ,,\ =0.11 \quad ,, \\ T=35.2 \quad ,, & ,,\ =0.20 \quad ,, \end{cases}$$

During the next $26^m\ 30^s$, the motion was more or less active and comprised a series of maximum groups, which occurred at an average interval of $4^m\ 48^s$; the elements of motion in the successive maxima being as follows :—

1st max. group............$\begin{cases} T=20.3 \text{ sec., ...} & 2a=0.36 \text{ mm.} \\ T=12.8 \quad ,, \text{ .....} & 2a=0.075 \quad ,, \end{cases}$

2nd ,, ,, ...$\begin{cases} T=22.7 \quad ,, \text{ .....} & 2a=0.44 \text{ mm.} \\ T=17.8 \quad ,, \text{ .....} & 2a=\text{(small).} \end{cases}$

3rd ,, ,, ...$\begin{cases} T=23.8 \quad ,, \text{ .....} & 2a=0.30 \text{ mm.} \\ T=18.8 \quad ,, \text{ .....} & 2a=0.10 \quad ,, \end{cases}$

$$\text{4th max. group}\cdots\cdots\cdots\cdots\begin{cases} T=19.7 \text{ sec.,}\ldots\ldots 2a=0.43 \text{ mm.} \\ T=16.5 \text{ ,, ,}\ldots\ldots 2a=0.19 \text{ ,,} \end{cases}$$

$$\text{5th ,, ,,}\cdots\cdots\cdots\cdots\begin{cases} T=20.8 \text{ sec.,}\ldots\ldots 2a=0.30 \text{ ,,} \\ T=14.4 \text{ ,, ,}\ldots\ldots \text{ ,, = (small).} \end{cases}$$

$$\text{6th ,, ,,}\cdots\cdots\cdots\cdots\begin{cases} T=21.1 \text{ sec.,}\ldots\ldots 2a=0.30 \text{ mm.} \\ T=16.0 \text{ ,, ,}\ldots\ldots \text{ ,, = (small).} \end{cases}$$

It will be observed that in each maximum group there were essentially two sets of vibrations, one of which formed the predominating constituent, while the other occurred only at minimum epochs ; the periods belonging to these two sets being as follows :—

$$(A) \text{ Larger vib. } \left\{\begin{array}{l} T=20.3 \text{ sec.} \\ \quad 22.7 \\ \quad 23.8 \\ \quad 19.7 \\ \quad 20.8 \\ \quad 21.1 \end{array}\right. \qquad (B) \text{ Smaller vib. } \left\{\begin{array}{l} T=12.8 \text{ sec} \\ \quad 17.8 \\ \quad 18.8 \\ \quad 16.5 \\ \quad 14.4 \\ \quad 16.0 \end{array}\right.$$

$$\text{mean}\ldots\ldots\ldots\ldots \mathbf{21.4} \qquad\qquad \text{mean}\ldots\ldots\ldots\ldots \mathbf{16.7}$$

The mean value of the (A) periods is 21.4 sec., while that of the (B) periods is 16.7 sec., (with the single exception of $T=12.8$ sec.). The difference between these two means is 4.7 sec., correponding probably to the fundamental period which I have denoted by P_1.[*]

The subsequent motion was much smaller :— $T=16.5$ sec.

(II) Diagrams from a Horizontal Tremor-recorder.

The two earthquakes have been registered also by a small Omori Horizontal Tremor-recoder, which was originally designed to record small local shocks. Each of the two horizontal component pendulums has a bob of 16 kgm weight, and an oscillation period of about 2 sec., the multiplication ratio being 45.*

---

[*] The *Publications*, Nos. 5, 13, 21, etc.

The times of commencement of the Aleutian and the Valparaiso earthquakes as recorded by the tremor-recorder were 0^h 17^m 17^s and 1^h 01^m 08^s (G.M.T.) respectively.

NS Component.

Aleutian Earthquake. The preliminary tremor lasted 5^m 30^s, during which the motion was most active and consisted of the following vibrations :—

$$\begin{cases} T=1.9 \text{ sec.,} & 2a=0.062 \text{ mm.} \\ T=5.4 \ ,, & \ ,, =0.038 \ ,, \end{cases}$$

The movements during the earlier parts of the principal portion were as follows :—

(i) For the 1st 2^m 37^s :—

$$T=6.4 \text{ sec.,} \qquad 2a=0.04 \text{ mm.}$$

(ii) For the next 2^m 59^s :— there were 6 slow and nearly uniform vibrations mixed with quick ones :—

$$\begin{cases} T=29.8 \text{ sec.,} & 2a=0.022 \text{ mm.} \\ T=\ 5.3 \ ,, & \ ,, =0.029 \text{ mm.} \end{cases}$$

The subsequent vibrations gradually diminished and were as follows :—

$$T=13.8 \text{ sec.,} \qquad 2a=0.022 \text{ mm.}$$

Valparaiso Earthquake. The commencement was indicated by small vibrations of $T=0.92$ sec.

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* This is exactly similar to the instrument which I have described in the *Publications*, No. 18, the only modification being the use of a cylinder for the recording surface.

EW Component.

Aleutian Earthquake. The preliminary Tremor :—

$T=2.3$ sec., $2a=0.067$ mm.

The movements in the successive parts of principal portion were as follows :—

(i) For the 1st $1^m\ 49^s$:—$T=$ 5.0 sec., $2a=0.022$ mm.
(ii) ,, ,, next 2 02 :—$T=30.5$,, $2a=$ (Small).
(iii) ,, ,, ,, 2 12 :—$T=22.0$,,
(iv) ,, ,, ,, 3 50 :—$T=17.7$,,

The motion in the E W component was much smaller than in the NS component. This may be due to some unequality in the friction existing between parts of the two horizontal pendulums.

Valparaiso Earthquake. During the first 55 sec., the motion was small. Then the vibrations became most active :—

$T=2.2$ sec., $2a=0.033$ mm.

$9^m\ 10^s$ after this maximum there was another slight one, which may correspond to the major arc propagation.

6. Observation at Manila. Pl. XXVI. ENE-WSW Component.

The record was obtained by a Vicentini seismograph. In the following analysis, the amplitude is given *unreduced*, or not divided by the multiplying ratio of the pointer.

Aleutian Earthquake. Commencement$=0^h\ 20^m\ 42^s$. For the first $5^m\ 49^s$, the motion consisted of quick vibrations :—

$$\begin{cases} T=2.4 \text{ sec.,} & 2a=3.5 \text{ mm (pendulum oscillation).} \\ T=4.8 \text{ ,,} & \end{cases}$$

For the next $5^m\ 14^s$:—

$$\begin{cases} \ T=\ 3.8 \text{ sec.,} & 2a=1.5 \text{ mm.} \\ \ T=\ 2.6 \text{ ,,} & 2a=1.0 \text{ ,,} \\ \ T=\ 7.9 \text{ ,,} & 2a=2.0 \text{ ,,} \\ (?)\ T=20.8 \text{ ,,} & \end{cases}$$

Thereafter the quick pendulum movements gradually decreased, till they disappeared at $0^h\ 38^m\ 20^s$; the principal vibrations being as follows :—

$$\begin{cases} T=11.2 \text{ sec.,} & 2a=1.4 \text{ mm.} \\ T=17.8 \text{ ,,} & 2a=2.6 \text{ ,,} \\ T=\ 4.7 \text{ ,,} & \text{(small)} \end{cases}$$

For the next $8^m\ 25^s$:—

$$\begin{cases} T=11.4 \text{ sec.,} & 2a=1.0 \text{ mm.} \\ T=\ 7.5 \text{ ,,} & 2a= \text{ (small.)} \end{cases}$$

For the next $5^m\ 4^s$:—

$$\begin{cases} T=20.4 \text{ sec.,} & 2a=0.9 \text{ mm.} \\ T=\ 9.3 \text{ ,,} & \text{(small).} \end{cases}$$

Then, at $0^h\ 51^m\ 49^s$, there took place 3 well defined slow vibrations :—

$$T=20.9 \text{ sec.,} \qquad 2a=1.5 \text{ mm.}$$

The subsequent motion was smaller :—

$$\begin{cases} T=17.2 \text{ sec.,} & 2a=1.0 \text{ mm.} \\ T=11.8 \text{ ,,} & 2a=1.4 \text{ ,,} \end{cases}$$

Valparaiso Earthquake. Commencement$=1^h\,00^m\,15^s$. The commencement was marked by the appearance of quick vibrations, the motion being small for the first $1^m\,6^s$. Then, at $1^h\,01^m\,21^s$, there appeared most active quick movements, which remained nearly uniform for the next $4^m\,33^s$:—

$$T=5.7 \text{ sec.}, \qquad 2a=2.4 \text{ mm.}$$

The quick vibrations were indicated distinctly till about $2^h\,19^m$, and slightly till $2^h\,29^m$, there being superpositions of slow movements :—

$$T=2.3 \text{ sec.}, \ldots\ldots\ldots\ldots\ldots\ldots 2a=2.0 \text{ mm.}$$

$$T=5.3 \text{ sec.};\ 7.4 \text{ sec.};\ 11.6 \text{ sec.};\ 14.6 \text{ sec.}$$

At $1^h\,07^m\,06^s$ there was some increase in the amplitude of the quick vibrations (max. $2a=2.0$ mm.), which were probably the major arc propagation.

7. *Observation at the Querce Observatory, Florence.* The following is a note on the lithographic reproduction of the diagrams* obtained at the Querce Observatory, Florence, by a pair of Stiattesi Horizontal Pendulums, whose instrumental constants are :—

Multiplication of the pointer=25.
Weight of the heavy mass=250 kgm.
Mean velocity of the record-receiver=97 cm. per hour.
(Complete) period of free pendulum oscillation=19.6 sec.

Aleutian Earthquake. Commencement=$0^h\ 24^m\ 00^s$.

NW–SE Component.

1st Preliminary Tremor. Duration=$10^m\ 53^s$.

The motion consisted of small uniform vibrations.

2nd Preliminary Tremor. Commencement=$0^h\ 34^m\ 53^s$. Duration=$11^m\ 41^s$:—

$T=17{,}3$ sec., $2a=0.22$ mm.

Principal Portion. Commencement=$0^h\ 46^m\ 34^s$. [1st and 2nd phases] Duration=$13^m\ 30^s$. For the first $7^m\ 47^s$, the motion consisted of slow vibrations :—

$T=36.0$ sec., $2a=0.36$ mm.

Then there set in large pendulum oscillations, which continued till $2^h\ 27^m$, thereby confusing the movements due to the Valparaiso earthquake. These oscillations were as follows :—

$T=18.1$ sec., $2a=6.9$ mm. (pend. oscillation).

NE–SW Component.

In this component diagram the pendulum oscillations were much smaller than the other.

1st Preliminary Tremor. Duration=$10^m\ 32^s$.

The vibrations were very small.

2nd Preliminary Tremor. Duration=$12^m\ 6^s$:—

$T=\ 9.7$ sec., $2a=0.10$ mm.; $T=14.6$ sec.

8. Summary of the Observations of the Aleutian Earthquake. The mean values of the different periods of vibrations, which occurred at Tokyo, Osaka, Manila, and Querce, are given in the following table, the periods most frequently occurring being printed in fat characters.

Periods of Vibration.

Tokyo. (EW)	Tokyo. (Vertical)	Tokyo. (NS)	Osaka. (EW)	Osaka. Horiz. Tremor Recorder.	Manila.	Querce.	*Mean.*
sec.	sec.	sec.	sec.		sec.	sec.	sec.
—	3.5	—	—	1.9 (pend 2.3 oscl.)	2.9	—	—
4.7	4.6	4.5	5.0	5.5	4.8	—	4.7
6.4	—	—	—	—	—	—	—
8.6	9.4	—	—	—	8.2*	9.7	8.8
10.7	11.5	—	10.6	—	11.5	—	11.1
—	—	—	—	13.8	—	—	13.8
18.8*	16.5	18.4	15.9	17.7	17.5*	17.7(P.O.)*	17.4
—	—	20.3	20.0*	—	20.7*	—	20.3
—	22.3*	—	—	22.0	—	—	22.2
26.1*	—	—	28.5(P.O.)*	—	—	—	27.3
30.9	—	30.7	—	30.2	—	—	30.6
36.0*	34.0*	33.8*	34.4	—	—	36.0*	34.8

It will be seen from the above table amongst others that the (mean) periods of 4.7 sec., 8.8 sec., 11.1 sec., 17.4 sec., 20.3 sec., 22.2 sec., 30.6 sec., and 34.8 sec. occurred at Tokyo as well as at one or more of the three other places, namely, Osaka, Manila, and Querce. (See also § 15.) The Tokyo records indicate that there was no special difference in the periods of vibration between the horizontal and vertical movements.

In the following table are collected the times of earthquake occurrence at the above mentioned four places, and at 25 other stations ; the data relating to the latter having been taken from the monthly or weekly reports published by the different seismological observatories. In a few cases, the time of occurrence of the 2nd preliminary tremor and the duration of the 1st preliminary tremor are also given.

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* The periods of the predominating vibrations are marked with *asterisks*.
(P.O.) marks the pendulum oscillations.

OBSERVATION OF THE ALEUTIAN EARTHQUAKE.

(Time in G.M.T.)

Place.	Position.		Time of occurrence $=t_1$	Time of commencement of 2nd P. T. $=t_2$	Duration of the 1st Preliminary Tremor.
	Latitude.	Longitude.			
Origin.........*	50° N	175° E	$0^h\ 11^m\ 44^s$		
					(Total P.T.)
Tokyo............	35° 42′ 29″ N	139°45′53″ E	$0^h\ 17^m\ 16^s$		$5^m\ 20^s$
Osaka	34 42 — N	135 31 — E	0 16 52		5 36
Mizusawa	39 08 — N	141 07 — E	0 16 57		
Taihoku(Formosa)	35 02 — N	121 30 — E	0 20 07		
Manila	14 34 41 N	120 58 33 E	0 20 42		
Zikawei.........	31 11 33 N	121 10 45 E	0 19 59		
Berkeley,Cal...	37 52 24 N	122 15 11 W	0 18 00		
Washington D.C...	38 54 18 N	77 03 06 W			
Göttingen	51 33 — N	9 58 — E	0 23 43	0 32 30	8 47
Strassburg......	48 35 00 N	7 46 10 E	0 23 01	———	13 33(?)
Heidelberg......	49 23 55 N	5 58 44 E	0 23 08		
Budapest........	47 22 29 N	19 03 55 E	0 23 34		
O'Gyalla..	47 52 21 N	18 52 32 E	0 22 42		
Zagreb...........	45 48 54 N	15 58 48 E	0 23 23		
Kremsmünster......	48 03′ — N	14 08′ — E	0 23 23	0 32 55	9 32
Laibach..........	46 03′ — N	14 31′ — E	0 23 37	0 34 08	10 31
Vienna	48 15′ — N	16 22′ — E	0 22 41	0 37 36	
Triest	45 39′ — N	13 46′ — E	0 23 25		
Tiflis	41 43 08 N	44 47 51 E	0 22 54		
Borshom...... .	41 51 — N	43 23 08 E	0 23 45		
Achalkalaki.. ..	41 25 — N	43 29 09 E	0 23 49		
Upsala..........	59 51 39 N	17 37 30 E	0 22 00		
Belgrad	44 48′ — N	20 09′ — E			
San Fernando (Spain).........	36 27 40 N	6 12 19 W	0 23 24		
Tortosa	40 49 — N	2 34 — E	0 23 21		
Coats Observatory (Paisley).........	55 51 — N	4 25 — W	0 31 36		
Querce (Florence)..	43 47 18 N	11 16 42 E	0 24 00		
Ximeniano („)...	43 46 40 N	11 15 24 E	0 24 00	0 35 30	11 30

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* The position of the origin has been determined by methods given in § 9. For the determination of the time of earthquake origin see § 11.

9. Determination of the Approximate Position of the Origin of the Aleutian Earthquake. The approximate position of the earthquake origin may be determined in two different ways, from seismographic observations made at a number of stations, as follows :—

(i) By a comparison of the times of earthquake occurrence ;

(ii) From the epicentral distances deduced from the durations of the preliminary tremors.

1*st Method* : *Comparison of the times of occurrence.* As an example, let us take the times $(=t_1)$ of earthquake occurrence at Tokyo, Florence, Manila, and Berkeley (California):—

Tokyo.......... ......$t_1=0^h\ 17^m\ 16^s$
Florence..............$t_1=0\ \ 24\ \ 00$
Manila..................$t_1=0\ \ 20\ \ 42$
Berkeley..............$t_1=0\ \ 18\ \ 00$

It is evident that among the above 4 stations Tokyo was nearest to the origin. As, further, the duration of the total preliminary tremor in Tokyo was $5^m\ 20^s$, which corresponds to an epicentral distance of about 25°, I shall assume a propagation velocity of 13^{km} per sec. for the differential epicentral distances between Tokyo, Berkeley, and Florence (Ximeniano and Querce.) For the comparison of Tokyo and Manila, however, let us take a somewhat lower velocity, say, 10^{km} per sec. Under these suppositions, we obtain the following results :—

Combination of places.	Difference of times of commencement.		Approximate Epicentral Difference.
Florence-Tokyo	6^m	44^s	47.°3
Manila-Tokyo..............	3	26	24.3
Berkeley-Tokyo..........	0	44	5.2

A circle drawn about Manila as centre with a radius of 24.°3 passes very nearly through Tokyo, while the locus of equidistanc between Tokyo and Florence intersects that between Tokyo and San Francisco at about $\varphi=57^\circ$ N, $\lambda=179^\circ$ W ; this latter point, or the epicentre, being situated, nearly in the same great circle which connects Tokyo and Manila.

2nd *Method : Comparison of the epicentral distances deduced from the duration of the preliminary tremor.* The relation of the epicentral distance (x) to the duration (y_1) of the 1st preliminary tremor, or the total duration (y) of the 1st and 2nd preliminary tremers, is approximately given by either of the two following equations*

$$\left\{\begin{array}{l} \overset{\text{km.}}{x}=17.1\ \overset{\text{sec.}}{y_1}-\overset{\text{km.}}{1360}. \\ x=\ 6.54\,y+720. \end{array}\right.$$

Taking the observations at Tokyo and Florence, (Ximeniano) for instance, we have :—

$$\left\{\begin{array}{l} \text{Tokyo}\ \ldots\ldots\ldots\ldots\ldots\ y=\ 5^{m}\ 20^{s}\,;\quad x=25^\circ.3 \\ \text{Florence}\ldots\ldots\ldots\ldots\ y_1=11\ \ \ 30\ \ ;\quad x=94. \end{array}\right.$$

If two circles be drawn about Tokyo and Florence as centres, with the radii of 25°.3 and 94° respectively, they intersect at about $\varphi=44^\circ$ N, $\lambda=170^\circ$ E.

Taking the mean of the two positions above obtained, we find, for the approximate situation of the earthquake origin,

$$\lambda=\ 50^\circ\ \text{N},\qquad \varphi=175^\circ\ \text{E}.$$

The epicentral distances of some of the observing stations are as follows :—

Tokyo	29°	08′
Osaka	32	26
Berkeley	45	22
Manila	58	25
Florence	85	09

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[*] The "Publications," No. 5 and No. 13.

10. *Aleutian Earthquake: Direction of Motion in Tokyo.* From a comparison of the descriptions of the EW and NS component diagrams (**III** and **IV**, § 4), we see that the displacement occurring at the very commencement of the earthquake was as follows:—

$$\begin{cases} 0.04 \text{ mm, towards W,} \\ 0.06 \quad \text{,, ,} \quad \text{,,} \quad \text{S;} \\ \text{Resultant motion} = 0.07 \text{ mm, towards S } 34^\circ \text{ W.} \end{cases}$$

Again the two displacements constituting the first vibration of the principal portion were as follows:—

$$(\text{i})\ldots\ldots\ldots\begin{cases} 0.25 \text{ mm, towards W,} \\ 0.24 \quad \text{,, ,} \quad \text{,,} \quad \text{S;} \\ \text{Resultant motion} = 0.34 \text{ mm, towards S } 46^\circ \text{ W.} \end{cases}$$

$$(\text{ii})\ldots\ldots\ldots\begin{cases} 0.43 \text{ mm, towards E,} \\ 0.38 \quad \text{,, ,} \quad \text{,,} \quad \text{N;} \\ \text{Resultant motion} = 0.57 \text{ mm, towards N } 49^\circ \text{ E.} \end{cases}$$

Taking the mean of these three results, we find that the direction of motion was

S 48° W – N 48° E.

This direction points very nearly towards the source of the earthquake disturbance located from the seismographic observations (§ 9), the actual direction of the centre from Tokyo being N 50° E. It will be observed that the initial or first displacement of vibration was directed away from the origin.

11. *Determination of the Approximate Time of Occurrence at the Origin of the Aleutian Earthquake.* The approximate time ($=t_0$) of earthquake occurrence at the origin can be estimated by means of the following equation*:—

$$t_0 = t_1 - 1.165\, y_1^{\text{sec.}}$$

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* The *Bulletin*, No. 1.

in which t_1 and y_1 are respectively the time of occurrence and the duration of the 1st preliminary tremor at any given station. Applying, for instance, the above formula to the observations made at Göttingen, Ximeniano, and Laibach, we obtain the following results:—

Göttingen .... $\begin{cases} t_1 = 0^h 23^m 43^s; \; y_1 = \;\; 8^m 47^s \\ t_0 = 0^h 13^m 28^s \end{cases}$

Ximeniano. .... $\begin{cases} t_1 = 0 \;\; 24 \;\; 00 \; ; \; y_1 = 11^m 30^s \\ t_0 = 0 \;\; 10 \;\; 35 \end{cases}$

Laibach.... .... $\begin{cases} t_1 = 0 \;\; 23 \;\; 37 \; ; \; y_1 = 10^m 31^s \\ t_0 = 0 \;\; 11 \;\; 19 \end{cases}$

Taking the mean of the above three values of the t_0, we find:—

t_0, or time of earthquake commencement $= \mathbf{0^h 11^m 44^s}$

12. ***Valparaiso Earthquake.*** According to newspaper reports, the Valparaiso earthquake happened a short time before 8 o'clock in the evening, of the 16th of August. As shown in § 13, the approximate time of occurrence in the epicentral district was probably $0^h 40^m 05^s$ (the 17th) in Greenwich Mean Time, or $7^h 53^m 29^s$ P.M. (the 16th) in the Valparaiso Local Time. At Valparaiso the weather on the day of the earthquake was unusually calm and pleasant.*

The earthquake and subsequent fires produced a considerable amount of damage in the city of Valparaiso; the shock having also caused a great destruction in Vina del Mar, Le Ligna, Limache, Quilque, Arriaca, Palequin, Meripilla, Quillota, Llaillai, Hierro

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* A fine and calm weather, which generally corresponds to the rise of the barometric presure, also characterized most of the great destructive earthquakes in Japan.

Viejo, Aberca, Conchall, Petarda, La Placilla, La Calera, Los Andes, San Felipe, and some other places. There were 30 deaths in the city of Santiago, while the town of Vallenar (300 miles north of the capital) is said to have been badly affected.

The strong motion area seems to have extended from Vallenar on the north to Santiago on the south, over a distance of about 300 miles. The earthquake origin was probably an elongated sub-oceanic zone parallel to the coast, the most central part of which may be assumed *roughly* to be at about 250 km to the NNW of Valparaiso, or at the following position:—

$$\varphi=31^\circ \text{ S}, \qquad \lambda=73^\circ \text{ W}.$$

According to a letter of Dr. Ricardo Poenisch, of Santiago, there was no surface manifestation of faults, but apparently the coast was elevated more than 1 metre. The shock was felt on the north as far as Tacna, the northern-most province of Chile, at a distance of about 450 miles from Valparaiso.

The epicentral distances of the different stations, where the distinct commencement of the Valparaiso earthquake was observed, are as follows:—

Tokyo	152° 22′
Osaka	155 51
Göttingen	109 46
Ximeniano	107 07
Manila	159 10

13. ***Observation of the Valparaiso Earthquake.*** The time (t_1) of occurrence observed at the different stations were as follows:—

Tokyo	$t_1=1^h00^m34^s$
Osaka	1 00 15
Mean	**1 00 25**
Manila	1 00 15
Göttingen	1 13 30 (?) (Vert. Seismograph.)
Ximeniano	0 58 15

The durations (y_1 and y_2) of the 1st and 2nd preliminary tremors were as follows:—

Tokyo	$y_1=18^m59^s$;	$y_2=26^m05^s$;	$y_1+y_2=45^m04^s$
Osaka	$y_1=15\ 48$;	$y_2=24\ 25$;	$y_1+y_2=40\ 13$
Mean	$y_1=$**17 24**;	$y_2=$**25 15**;	$y_1+y_2=$**42 39**

Time (t_5) of commencement of the 3rd phase of the principal portion was as follows:—

Tokyo	$t_5=1^h52^m18^s$	(Vertical component)
„	1 58 53	(EW „)
Osaka	1 54 21	(„ „)
Mean	**1 55 11**	

W_2 Motion. The time intervals between the corresponding epochs in the 1st preliminary tremor of the W_1 and W_2 waves, at Tokyo, Osaka and Manila, were as follows:—

Tokyo	6^m35^s (Vertical) 7 45 (EW component)
Osaka	9 32
Manila	5 45

The identification of the W_2 motion was in each case extremely difficult, and the intervals of time above given are to be regarded only as rough estimates. Taking the mean, we obtain a time interval of 7^m24^s, corresponding to a mean epicentral distance of 155° 48′. The theoretical time interval corresponding to the latter value of the epicentral distance, would be, if we suppose a propagation velocity of 13 km per sec., equivalent to

$$\frac{360^\circ-(2\times 155^\circ 48')}{13}=6^m54^s$$

14. ***Estimation of the Time (t_0) of Occurrence at the Origin of the Valparaiso Earthquake.*** Taking the mean of the Tokyo and Osaka observations, we have, according to the equation in § 11,

$$\begin{cases} t_1=1^h00^m25^s \\ y_1=17^m24^s \\ t_0=t_1-1{\cdot}165\ y_1=0^h40^m05^s\ \text{(G.M.T.)} \end{cases}$$

Now the Valparaiso mean local time is that of longitude 71° 39′ W, or $4^h46^m36^s$ after G.M.T. We have, therefore,

$$t_0=7^h53^m29^s\ \text{P.M. (Local time).}$$

15. ***Comparison of the Periods of Vibration in the Valparaiso Earthquake with those in the Caracas and Guatemala Earthquakes.*** The following table gives the mean values of the different periods found in the seismograms obtained at Tokyo, Osaka, and Manila, together with those found in the Tokyo seismograms of the Caracas earthquake of Oct. 29, 1900, and the Guatemala earthquake of April 19, 1902; the periods of more frequent occurrence being printed in fat characters.

Caracas and Guatemala Earthquakes.	Valparaiso Earthquake.				
Tokyo (Horizonal).	Tokyo (Horizontal).	Tokyo (Vertical).	Osaka (EW).	Manila.	*Mean.*
Sec	Sec.	Sec.	Sec.	Sec.	Sec.
2.9	—	—	2.4	—	—
—	4.0	3.5	3.9	5.5	4.0
7.9	9.0	—	8.0	7.4	8.4
10.2	11.5	11.2	10.4 12.4	11.6	11.4
14.8	15.7	—	14.0 16.0	14.6	15.1
18.4	17.7	18.2	19.1	—	18.3
21.2	22.3	22.4	23.0	—	22.6
		26.8			26.8
26.9	29.7	—	27.7	—	28.7
32.9	32.7	—	31.7	—	32.4
39.5	37.7	—	36.8	—	37.1
45.4	—	—	45.0(?)	—	45.0(?)
56.0	—	—	—	—	—
—	—	—	67.4(?)	—	67.4(?)

From the above table it will be seen that the different periods of vibration, which occurred at Tokyo in the Caracas and Guatemala earthquakes, were almost perfectly identical with those which occurred at Tokyo and Osaka in the Valparaiso earthquake. The Manila seismogram indicates only shorter periods, which are also found in the Tokyo and Osaka records. It is almost certain that, if the Manila seismograph had a long natural period of oscillation, other slow periods would have been likewise registered there. It may be here mentioned that I have taken, for comparison, the

Caracas and Guatemala earthquakes, as the origins of these shocks had, with respect to Tokyo, epicentral distances and azimuths not widely different from those of the Valparaiso earthquake.

By comparing the above table with the list of periods in § 8, it will be seen that the periods of vibration in the A'eutian earthquake also occurred in the Central and South America earthquakes.

The examination of the numerous seismographic records of the great Indian earthquake of April 4, 1905, has also shown the common occurrence of various periods of vibration in different parts of the would.

From the facts like the above, it seems probable that the microseismic or unfelt and slow periods of vibration are approximately the same in different earthquakes and at different stations. I have previously stated a similar conclusion with regard to the *pulsatory oscillations.*

Sea Waves.

16. ***Tidal Disturbances due to the Valparaiso Earthquake.*** The earthquake caused some tidal disturbances, which spread over the Pacific. Thus, in the enclosed Bay of Maalaea, on the island of Maui (Hawaii) the wave is said to have reached a height of 12 feet. An inter-island steamer Noeu, while anchored off the north-eastern coast of the island of Hawaii in a calm sea was carried forward by a sudden undertow, which was so strong that her chain parted and she lost her anchor and forty fathoms of chain. It is, however, noteworthy that there were apparently no sea waves at Valparaiso itself, there being no newspaper account of such disturbances at the Chilian port. The fact seems to be that the tidal waves in the vicinity of Valparaiso did not, owing to the great depth of the water along the coast, attain any considerable amount, failing thereby to produce damage or attract attention.

16. *The Sea Waves observed at Honolulu, San Diego and San Francisco.* The tidal disturbances due to the Valparaiso earthquake, recorded on the tide gauges at Honolulu, San Diego, and San Francisco, whose *direct* arcual distances from the origin of disturbance are respectively 96° 21′, 76° 12′, and 82° 52′, were as follows.[*]

Honolulu.

$\varphi = 21° 18' \text{N}$; $\lambda = 157° \text{W}$.

The time used is that of longitude 157° 30′ W, or $10^h\ 30^m$ after G.M.T.

Slight traces of disturbances appeared at about 3 A.M. (Aug. 17th), the period being 33.3^{min}. But the distinct movement began first at $5^h\ 15^m$ A.M., and remained active for the next 20 hours :—

$T = 25.5$ min., $2a = 0.28$ ft.

In the subsequent portion, (the movement continued more or less active till Aug. 19th):—

$$\begin{cases} T = 26.3 \text{ min.,} & 2a = 0.15 \text{ ft.} \\ T = 45.3 \text{ ,,} & \end{cases}$$

San Diego.

U.S. Quarantine Wharf. $\varphi = 32° 42' \text{N}$; $\lambda = 117° 10' \text{W}$.

The time is the Western States Time, or 8 hours after G.M.T.

The movement was indicated distinctly first at $6^h\ 30^m$ A.M., and remained active till about $6^h\ 40^m$ P.M. :—

---

[*] Denoting by T and $2a$ the complete period and the range, or double amplitude, of the wave motion.

$$\left\{\begin{array}{ll} T=21.8\text{ min.,} & 2a=0.45\text{ ft.} \\ T=16.2\ \ ,, & \\ T=59.1\ \ ,, & \end{array}\right.$$

San Francisco.

Presidio. $\varphi=37°\ 48'$ N ; $\lambda=122°\ 30'$ W.
Time used : The Western States Time.

The distinct movement began at $7^h\ 42^m$ A.M., remaining active till about 11^h P.M. Up to about $8^h\ 30^m$ P.M., the predominating oscillations were as follows:—

$$\left\{\begin{array}{ll} T=59.1\text{ mm.,} & 2a=0.28\text{ ft.} \\ T=21.3\ \ ,, & \end{array}\right.$$

Thereafter the oscillations were as follows:—

$$\left\{\begin{array}{ll} T=41.0\text{ mm.,} & 2a=0.28\text{ ft.} \\ T=25.2\ \ ,, & 2a=0.24\ \ ,, \end{array}\right.$$

17. *The Sea Waves observed at Japanese Coasts.* The sea waves due to the Valparaiso earthquake were also recorded at the different tide-gauge stations on the Pacific coasts of Japan. The following is a short description of the mareogram obtained at Kushimoto, a small sea port situated at the southern extremity of the Kii peninsula.

(1) *Kushimoto.* $\varphi=33°\ 27'$ N ; $\lambda=135°\ 45'$ E.
Time used is that of longitude 135° E.

The sea waves began to appear at $9^h\ 27^m$ A.M., Aug. 18th. For the first 41^m, there were two small oscillations, of T=20.5 *min.* For the next $2^h\ 49.5^m$, there were 8 oscillations of T= 21.2 *min.*, whose magnitude gradually increased, the 7th having the maximum motion of 44 *cm.* The very initial motion was directed upwards ($2a=6$ *cm.*)

For the next $4^h\ 25^m$, the movement became smaller, the predominating period being shorter:—

$T=11.9$ mm., $2a=10$ cm

Thereafter the movement became again larger and slower:—

$T=22.3$ mm., $2a=16.5$ cm.

(ii) *Hakodate*: $\varphi=41°\ 46'$ N; $\lambda=140°\ 44'$ E.
Ayukawa: $\varphi=38°\ 18'$ N; $\lambda=141°\ 31'$ E.
Misaki: $\varphi=35°\ 9'$ N; $\lambda=139°\ 37'$ E.

The times of commencement of the sea waves at these three places were as follows* :—

Hakodate	10.02 A.M.,	Aug.	18th.
Ayukawa	9.29 ,,	,,	,,
Misaki...	8.23 ,,	,,	,,

I have also examined the mareograms obtained at the stations on the Japan Sea side. But these gave no clear evidence of the existence of the sea waves due to the earthquake in question.

18. ***The Velocity of Propagation across the Pacific.*** As is well known, the propagation velocity (v or v') of sea waves may be calculated in two different ways as follows:—

$$v=\frac{s}{\delta t} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$v'=\sqrt{gh} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In (1), s denote the distance between the earthquake origin and a given tide-gauge station, δt being the time interval taken by the sea waves in traversing that distance. In (2), g is the acceleration due to the gravity and h the mean sea depth along the distance s.*

---

* Taken from Dr. K. Honda's paper: *On the Velocity of Sea Waves through the Pacific.* Tokyo Sugaku-Buturigakkwai Kizi-Gaiyo. Vol. III, No. 9.

Kushimoto. Accorning to § 11, the time of earthquake occurrence at the origin was $0^h\ 40^m\ 05$ (G.M.T.). Hence :—

$$\delta t = 23^h\ 47^m.$$

The great circle connecting Kushimoto with the earthquake origin ($\varphi=31°$S, $\lambda=73°$W) is 155.°5 ($=s$) in length, passing on the whole through deeper parts of the Pacific. The mean depth h is about 4470 metres. We thus obtain:—

$$\begin{cases} v = 202 \text{ metres/sec.} \\ v' = \sqrt{gh} = 209 \text{ metres/sec.} \end{cases}$$

Honolulu. For the Honolulu observation, we have:—

$$s = 96°\ 21' ; \qquad \delta t = 15^h\ 05^m ;$$

s being the distance along the great circle connecting Honolulu with the earthquake origin, along which the mean depth h is about 4150 metres. We have therefore:—

$$\begin{cases} v = \dfrac{s}{\delta t} = 197 \text{ metres/sec.} \\ v' = \sqrt{gh} = 201.6 \text{ metres/sec.} \end{cases}$$

In these two cases, the agreement between the velocities calculated by the two different methods are in fair agreement with one another.

San Francisco and *San Diego.* The time intervals δt for San Francisco and San Diego were respectively $15^h\ 02^m$ and $13^h\ 50^m$. The great circles between these two places and the earthquake origin, whose lengths (s) are 82° 52′ and 76° 12′, pass very closely off the coast, the mean depths (h), measured a little outward (or westward) of these arcs, being respectively about 4210 and 4220 metres. We thus obtain:—

---

* A correction to the formula (2) has been given by Dr. C. Davison. *Phil. Mag.*, Jan. 1897.

San Francisco.............. $\begin{cases} v = \dfrac{s}{\delta t} = 170 \text{ metres/sec.} \\ v' = \sqrt{gh} = 203 \quad \text{,,} \quad \text{,,} \end{cases}$

San Diego .... $\begin{cases} v = \dfrac{s}{\delta t} = 170 \quad \text{,,} \quad \text{,,} \\ v' = \sqrt{gh} = 203 \quad \text{,,} \quad \text{,,} \end{cases}$

In each of these two cases, the actual velocity v is much smaller than that deduced from the mean sea depth, the discrepancy being probably due to the inexactness of the assumed wave path, which runs parallel to the coast.

19. ***Conclusion.*** The foregoing are only fragmentary notes on the Valparaiso and Aleutian earthquakes. A fuller account of the sea waves propagated across the Pacific will be given in a future number of the "Bulletin."

Tokyo. Jan., 1907.

On the Distribution of Recent Japan Earthquakes.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

I. PRELIMINARY.

1. *Arrangements of Earthquake Zones.* Let *A* (Fig. 1) represent a portion of the earth's surface, which is being depressed down. Then it can easily be demonstrated that there will be formed in the surrounding region two systems of weak lines, as shown in the figure. These are, *firstly*, concentric arcs, and *secondly*, radial lines, corresponding respectively to the dislocations and the cracks in the earth's crust.

Fig. 1

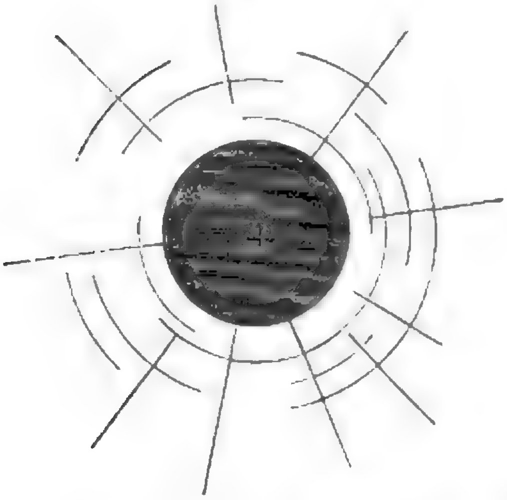
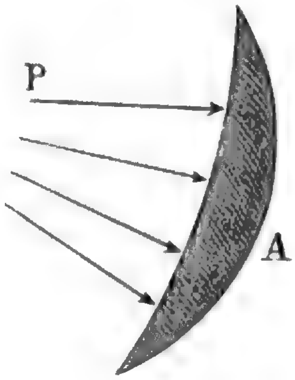


Fig. 2



Let us next vary slightly our supposition, and assume *A* (Fig. 2) to be a portion of the earth's surface, which is pushed from one side by a pressure *P*. In this case there will be formed two systems of the weak lines, similar to those mentioned above ; the concentric lines, however, becoming in this case foldings in the earth's crust. One of the consequences of the existence of the horizontal pressure P is that the outer (or convex) and the inner (or concave) sides of the region under consideration differ materially in the topographical features ; the former being much steeper in gradient than the latter. (See also Fig. 4). A may be a great mountain chain or a series of islands, arranged in a curvilinear form.

2. *Japanese Islands.* Fig. 2 is a diagrammatic representation of the Japanese islands, which, as shown in Fig. 3, forms a circular arc, whose convex and concave sides are turned toward the Pacific Ocean and Japan Sea respectively ; a glance at any map of Japan suggesting the idea that the islands were caused to assume their curvilinear form by the pressures acting from the Japan Sea side. The difference in the steepness of the gradient between the two sides of the island arc of Japan is illustrated in Fig. 4, which gives an ideal cross section of the latter.

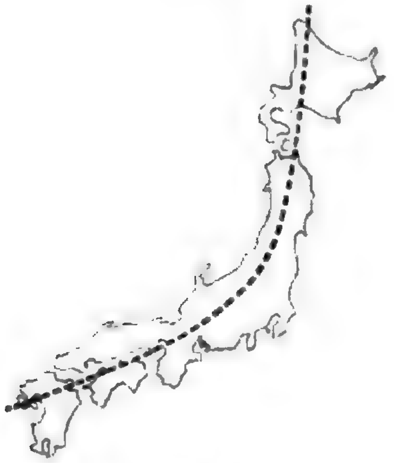


Fig. 3

The dotted line shows the general curve form of Japanese islands.

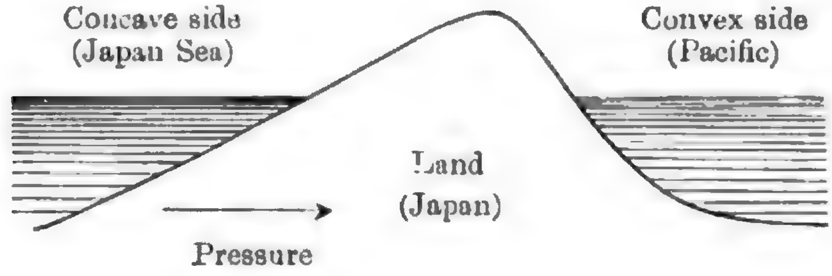


Fig. 4

As is well known, the Japan Sea is shallow and its greatest depth is only 3000 metres ; the gradient of the sea bottom, which is shallow, varying from 1 in 67 (off the coasts of Uzen and Ugo) to 1 in 110 (off the coasts of San-in Do provinces). The average gradient to the basin of 1000 metre depth from the west coasts of Hokkaido is 1 in 220. On the other hand, the Pacific Ocean is very deep, the Tuscarora basin, which lies off the northeastern coasts of Japan, reaching the depth of over 8000 metres at distances of 180 to 380^{km} from the coasts. The gradient of the Pacific bottom is much steeper than in the case of the Japan Sea, being, for example, as follows :—

Off the coast of Nemuro	1 in 27
,, NE ,, ,, Main Island	1 in 30
,, coast of Kii (to 5000 metres depth)	1 in 24
,, ,, ,, Tosa (,,)	1 in 32
,, SE coast of Kazusa and Awa (to 3000 metres depth) ...	1 in 16

3. ***Himalayas.*** The Himalayan mountain ranges furnish also a good example of the relation between the curvature and the steepness of the gradient, and form, as diagrammatically shown in

Fig. 5.
Showing the general course of the Himalayas.

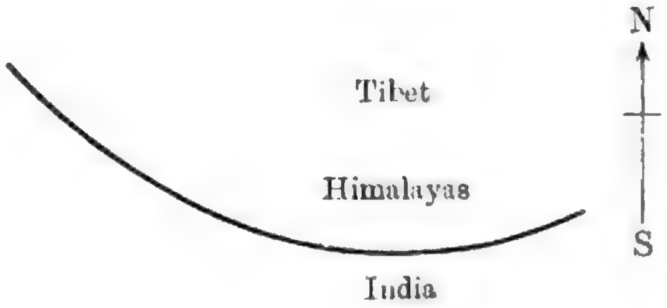


Fig. 5, a very beautiful circular arc extending in an east-west direction. The convex, or southern, side is very steep, the great mountains rising almost abruptly from the flat plane grounds of

India. On the other hand, the concave, or northern, side is not steep, constituting the plateau of Tibet.

4. *Sumatra and Java.* The two islands of Sumatra and Java also form together an arc, as indicated by the dotted curve in Fig. 6. The sea on the concave, or north-eartern, side is shallow (under 200 metres), while that on the convex, or south-western side is much deeper (over 5000 metres); it being also noteworthy that, in the case of Sumatra, mountain ranges lie close to the convex side.

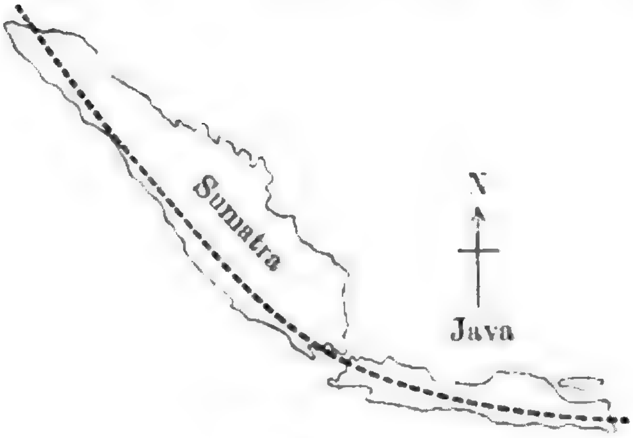


Fig. 6.
The dotted line indicates the general curvature of the two islands of Sumatra and Java.

5. *Aleutian Islands.* The Aleutian islands form a regular arc stretching in an east-west direction. Here again, the sea on the convex (southern) side is much deeper than that on the concave (northern) side. (See the preceding Article.)

6. *Relation between the Curvature and the Seismic Activity.* In simple cases, like those above mentioned in which there is a regular arc of mountain ranges or series of islands, the convex side is often shaken by great earthquakes, while the concave side is disturbed only by occasional local shocks.

7. *Distribution of Destructive Earthquakes in Japan.** The origins of the 221 destructive earthquakes of Japan proper, which happened between the 5th century and the present time, were approximately as follows:—

---

* A very valuable investigation on the distribution of small Japan earthquakes of recent years has been given by Count F. de Montessus de Ballore in *Archives des Sciences Phys. et Nat.* 1897.

Inland origins	114
Pacific "	47
Japan Sea origins	17
Inland Sea "	2
(*unknown*	41)

Again, among the above-mentioned 224 earthquakes, there were 10, which were very extensive and violent. Of these, 3 happened in central Japan, while the remaining 7 originated off the south-eastern coast of the Japanese islands, each being accompanied by great tidal waves.

A consequence of the difference in the seismic activities of the two sides of the Japan arc is that there were on the Pacific coast, 23 great tidal disturbances of seismic origin, while on the Japan Sea coast there were only 5 small cases of such disturbances.

II. RECENT STRONG JAPAN EARTHQUAKES.

8. *Distribution of the Origins of Strong Japan Earthquakes in Recent Years.* The systematic earthquake observation in Japan was commenced in 1885, and there were, during the next 21 years, 257 earthquakes which originated in or around Japan, and some of which were destructive or semi-destructive, the rest being strong or moderate shocks, each with a land area of disturbance* greater than about 4,000 square *ri*, or 25,000 square miles. The origins of these 257 earthquakes were distributed among the following 23 groups.

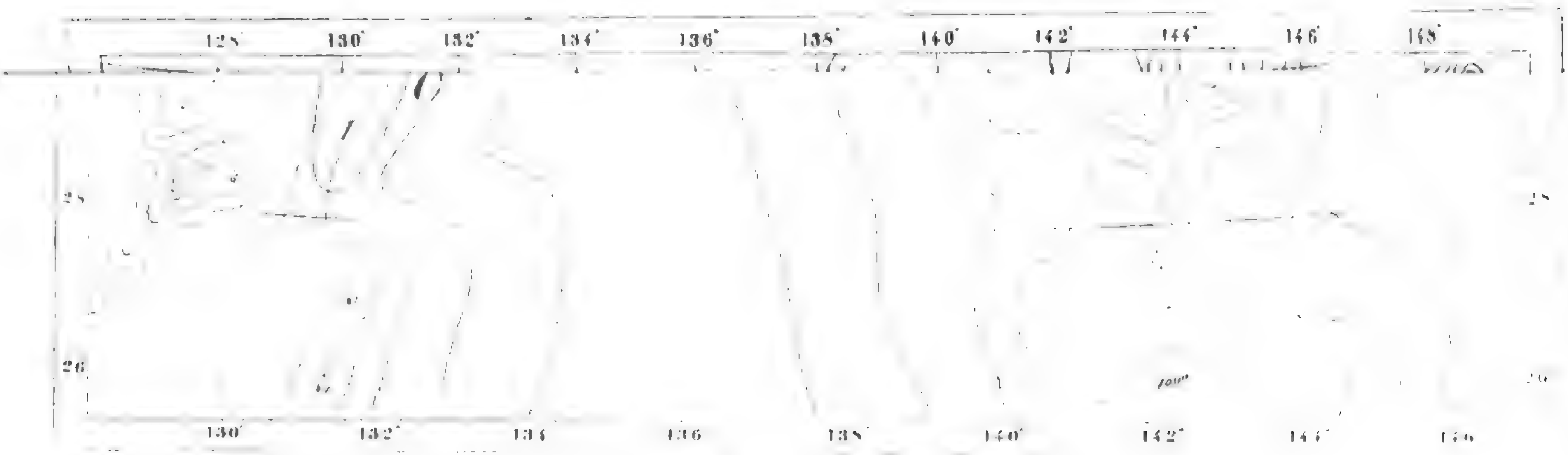
---

* The *area of disturbance* signifies the area within which the earthquake motion was *sensible*.

10
130
120
110
100
90
80
70
60
50
40
30
20

Fig. 8. Distribution of Strong Earthquakes in and about Japan.

(1885–1905.)


128°
130°
132°
134°
136°
138°
140°
142°
144°
146°
148°
28
26
1000
130°
132°
134
136
138
140°
142°
144
146

Boundary of provinces.

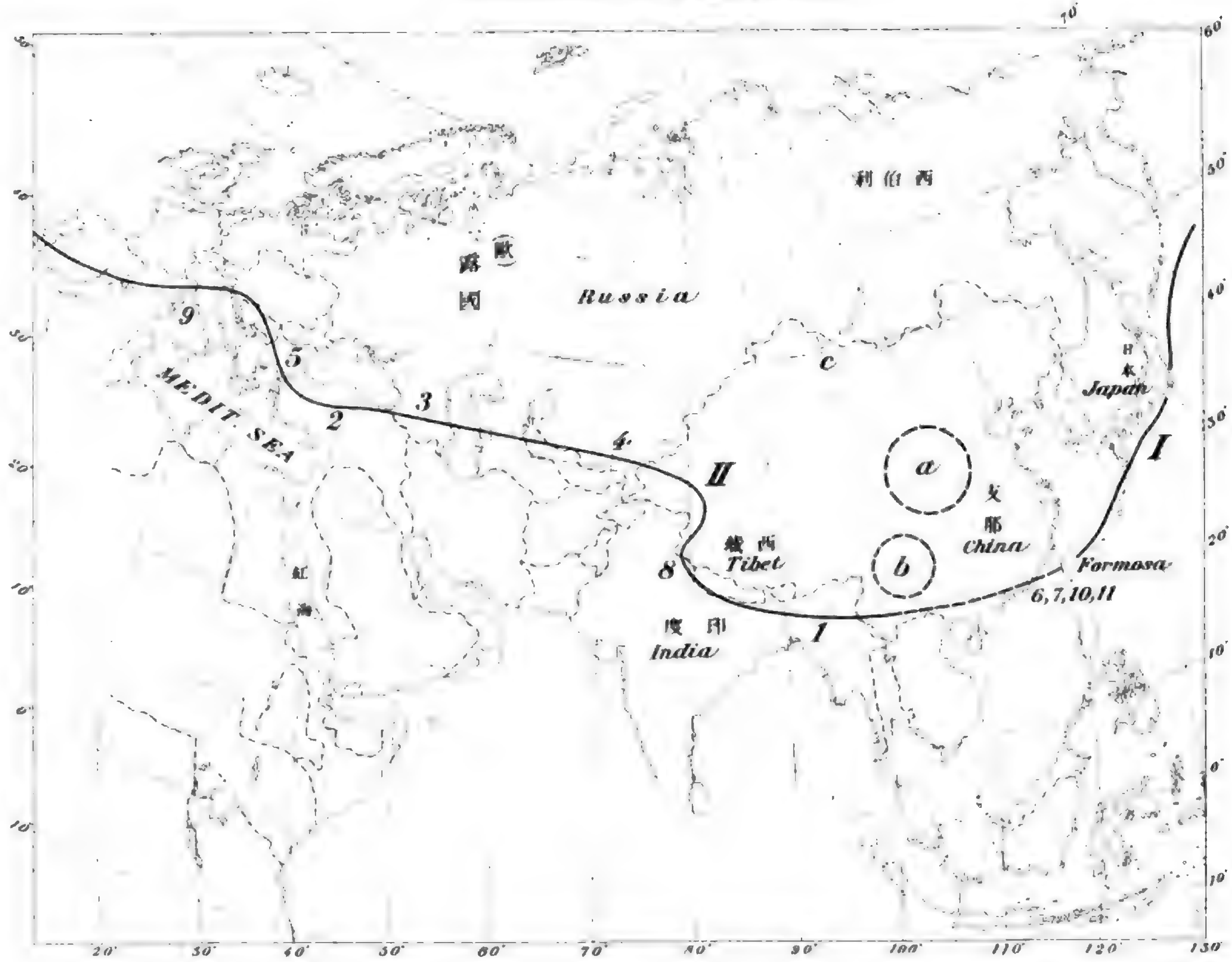
Blue curves are lines of equal depth, the figures giving the depth in metres.

Figures in red give the numbers of strong earthquakes which originated in the different parts.

10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°

PL. XXIX.

Fig. 9. Map Showing Recent Seismic Activity along the Mediterranean and Himalayas Zone.


西伯利
欧
露
国
Russia
9
5
MEDIT. SEA
2
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II
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a
b
支
那
China
日
本
Japan
I
西蔵
Tibet
8
Formosa
6,7,10,11
印度
India
1
紅
海
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
10°
0°
10°
20°
30°
40°
50°
60°
70°

A. *Off the SE coast of Hokkaido and the E coast of the Main Island.* The 138 earthquakes belonging to this group may be subdivided as follows:—

i.	Off the coasts of Nemuro and Kushiro	25
ii.	Between Hidaka and Mutsu	2
iii.	Off the coasts of Mutsu and Rikuchu	31
iv.	,, ,, Rikuzen	28
v.	,, ,, Iwaki	19
vi.	,, ,, Hitachi	14
vii.	,, eastern coast of the Kazusa-Awa Peninsula	11
viii.	,, coast of Izu	8
B.	*Off the E coast of Kii*	1
C.	,, *SE coast of Kyushu:—*	
i.	In the S part of the Hyuga Nada	3
ii.	,, Vicinity of Yaku and Tane Islands	3
iii.	To the E of Ōshima	1
D.	*Off the W coast of Kii*	1
E.	,, *Cape of Muroto (Tosa)*	1
F.	*Akita and Shōnai District:—*	
i.	Off the coast of Akita	1
ii.	Vicinity of Sakata	1
G.	*Vicinity of Noto:—*	
i.	Off the coast of Toyama (Etchu)	1
ii.	,, W coast of the Peninsula	3
H.	*Hoki and Izumo:—*	
i.	Off the coast of Hoki	1
ii.	,, ,, ,, Izumo	2
I.	*Western part of Rikuchu and Eastern Part of Ugo*	3
J.	*Musashi and Shimōsa District:—*	

	i.	NE Part of Musashi	5
	ii.	W Part of Shimosa	4
	iii.	W Part of Hitachi	1
	iv.	S Part of Shimotsuke	2
K.		*Tokyo Bay and Sagami-Nada*:—	
	i.	In Tokyo Bay	9
	ii.	„ Sagami-Nada	2
	iii.	„ Uraga Channel	1
L.		*Sagami, Kai and Suruga District*	5
M.		*Echigo, Shinano, and Hida District*:—	
	i.	Central and W Parts of Echigo	5
	ii.	N Part of Shinano	8
	iii.	E and S Parts of Hida	3
N.		*Mino, Owari, and Echizen District*:—	
	i.	Mino	9
	ii.	Mino and Echizen	1
	iii.	Owari and Mikawa	1
	iv.	In Owari Bay	1
O.		*Vicinity of the Lake Biwa*	1
P.		*Western half of the Inland Sea*	23
Q.		*W Part of Chikuzen*	2
R.		*Vicinity of Kumamoto*	3
S.		*In the S Part of Satsuma, and off the W coast of the Peninsula*	3
T.		*Vicinity of the Ishigaki Island (Loo Choo)*	1
U.		,, ,, *Yaeyama* ,, (,,)	1
V.		*Off the E coast of Formosa*	4
W.		*In the SW Part of Formosa*	2

Fig. 8 illustrates the distribution of the earthquake origins as tabulated above ; Fig. 7, which serves as a key map, giving the names of the different provinces. It will be seen that the most active seismic zone at present is ***A***, or that stretching off the eastern coasts of Hokkaido and Main Island, the number of the earthquakes which occurred in these parts of the Pacific Ocean amounting to 138, or more than half of the total number of the shocks relating to whole Japan. The zone, ***a***, marked by a thick dotted line, represents the approximate focus of the great earthquake* of the 4th year of the Hoyei period (Oct. 28, 1707); the two great shocks in the 1st year of the Ansei period (Dec. 23 and 24, 1854) originating respectively at the eastern half (between Kii and Izu) and the western half (between Kii and Kyushu) of this zone. ***A*** is evidently continued to ***a***, which is itself again continued to the zone ***C***, stretching from the southern part of Hyuga Nada to the east of Ōshima.

A, ***a***, and ***C*** together form the principal sub-oceanic earthquake zone of Japan, which runs parallel to the convex side of the latter and may be named *external seismic zone*. In former times ***a*** was most active, but at present ***A*** is very active.

On the Japan Sea side, there are three seismic regions ***F*** (Akita and Shōnai), ***G*** (vicinity of Noto), and ***H*** (Hōki and Izumo), whose activity is far less than that of the *external seismic zone* above mentioned. Of these three regions, the most important is ***F***, which in historical times produced some violent shocks. ***b*** and ***c*** represent respectively the approximate positions of the great Sado and Shōnai earthquake of Dec. 7, 1833, and the Hamada (Iwami) earthquake of March 14, 1872. These two latter regions form, together with ***F***, ***G***, and ***H***, a continuous band along the concave side of the Japanese islands, and may be termed the *inner seismic zone.*

---

* This was the greatest among the earthquakes which ever shook Japan.

Among the other earthquake districts, the most active are:— **M**, which mainly coincides with the valley of the Shinano-*gawa* and extends from the middle part of Echigo to the northern part of Shinano and the eastern part of Hida; **K**, Tokyo Bay and Sagami-*Nada*; **N**, Mino, Owari and Echizen District; and **P**, the western half of the Inland Sea.

The different earthquake districts shown in Fig. 8 may be divided into two systems, namely, the "concentric" and the "radial," as mentioned in §1. To the "concentric" system belong the *external* and *inner seismic* zones; **M** (Echigo, Shinano and Hida); **K** (Tokyo Bay and Sagami-*Nada*); **P** (Inland Sea), etc. Among the "radial" districts, the most conspicuous is **N**, or the Mino, Owari and Echizen zone.

9. Seismic Activity along the Mediterranean-Himalayan Zone. Fig. 9 indicates the approximate positions of 11 recent destructive earthquakes belonging to the Mediterranean-Himalayan Zone (marked II), provisionally supposed to extend eastwards to Formosa,* as follows:—

1. Assam and Bengal, June 12, 1897.
2. Aidin (Smyrna), Sept. 20, 1899.
3. Schemacha (Caucasus), Feb. 13, 1902.
4. Kashugar (Turkestan), Aug. 22, 1902.
5. Saloniki (Macedonia), April 4, 1904.

6, 7, 10, 11. Formosa, April 24 and Nov. 6, 1904, and March 17 and April 14, 1906.

---

* See the *Bulletin*, No. 1, p p. 20—24.

8. Kangra Valley (Punjab, India), April 4, 1905.
9. Calabria (Italy), Sept. 8, 1905.

a, *b* and *c* in the figure indicate the existence of seismic centres in China and the Baikal district, the two former being for the present in a quiet condition. Of the 11 earthquakes, Nos. 1, 2, 4, 5, 8 and 9 were very great disturbances and happened at *different* places along the zone in question.

10. *Relation of Japan Arc to Mediterranean-Himalayan and American Zones.* The most active, or external, seismic zone of Japan (I, Fig. 8) forms a connecting link between the Mediterranean-Himalayan zone and the great American zone, which latter stretches along or off the Pacific coast from Chile on the south to Alaska on the north;[‡] the Aleutian Island earthquake of Aug. 17, 1906, having finally brought the manifestation of the great seismic activity to within 2000^{km} of the north Japan.

[‡] See this Number, p. 100.

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Note on the Direction and Magnitude of the Vibrations in the Different Phases of the Earthquake Motion.*

By

A. Imamura, Sc. D.,

Extraordinary Member of the Imperial Earthquake Investigation Committee.

1. The present note contains the result of study on the observations at Tokyo concerning the magnitude and direction of seismic movements originating from distant centres. The direction of movements is examined with reference to the path of the wave transit, which is assumed to coincide with the great circle passing through the observing station and epicentre; the calculation being made according to the formula

$$\cos\frac{\Delta}{2} = \sqrt{\frac{\sin\frac{-\varphi+\varphi'+\delta}{2}\cos\frac{\varphi+\varphi'-\delta}{2}}{\sin\delta\cos\varphi}}$$

where Δ represents the angle between the great circle and the meridian of the observing station, δ the angular epicentral distance at the latter, and φ and φ' the latitudes of the station and the epicentre respectively.† The direction of the seismic motion has been obtained by composing the two horizontal movements of a few well-defined vibrations at the beginning of the different phases in the seismograms, which were given by Omori H. P. Seismographs registering EW and NS motions.

---

* Abstract of a paper read before the meeting of the Imp. Earthq. Inv. Comm. on Dec. 5, 1906, with addition of the discussion of earthquakes Nos. 4 and 9.

† The formula for the calculation of δ is $\cos\delta = \sin\varphi\sin\varphi' + \cos\varphi\cos\varphi'\cos(\lambda-\lambda')$, where λ and λ' represent the longitudes of the observing station and the epicentre respectively.

2. The earthquakes taken into consideration are as follows:—

TABLE I.

Group.	No.	Date.	Epicentre: λ	φ	δ	Δ
I	1	Sept. 29, 1899	Ceram. 129°E	6°S	42° 54'.6	S 13°.8 W
	2	July 29, 1900	New Hebrides. 175°E	17°S	59° 58'.6	S 33°.8 E
	3	June 1, 1906	N. Australia. 139°E	13°S	48° 42'.4	S 1°.1 W
	4	Nov. 19, 1906	W. Australia. 104°50'E	21°27'S	66° 1'.8	S 35°.7 W
II	5	Aug. 22, 1902	Turkestan. 75°E	39°.5N	50° 20'.1	N 65°.1 W
	6	April 4, 1905	India. 77°E	31°.8N	51° 26'.4	N 75°.1 W
III	7	Oct. 9, 1900	Alasca. 140°W	60°N	54° 57'.2	N 37°.0 E
	8	April 18, 1906	San Francisco. 123°W	38°.3N	73° 29'.3	N 54°.2 E
	9	Jan. 31, 1906	Columbia. 79°W	5°N	125° 26'.7	N 50.°0 E

Of these, the first four originated in Javan district, the next two in the Himalayan district, and the last three in the Pacific side of America. Thus the earthquakes in Groups I, II and III were propagated to Tokyo nearly from south, west, and north-east, respectively.

3. The positions of the epicentres given in the table were obtained as centres of the most disturbed areas, except for the suboceanic earthquakes Nos. 2–4, whose origins were determined by means of the following observations concerning the time of commencement.*

No. 2:—$7^h\ 8.7^m$ at Tokyo, $7^h\ 9.7^m$ at Batavia, $7^h\ 11.7^m$ at Calcutta, $7^h\ 12.0^m$ at Victoria, $7^h\ 15.2^m$ at Mauritius, $7^h\ 17.8^m$ at Cape of Good Hope.

No. 3:—$4^h\ 38.2^m$ at Tokyo (dur. of p. t. $=8^m\ 25^s$), $4^h\ 38.2^m$ at

---

* Time is given in Greenwich mean time.

Osaka (dur. of p. t.$=8^m$ 25^s), 4^h 35.8^m at Perth, 4^h 37.1^m at Batavia, 4^h 41.9^m at Bombay, 4^h 39.8^m at Calcutta.

No. 4:—7^h 28.9^m at Tokyo (dur. of p. t.$=16^m$ 13^s), 7^h 20.5^m at Perth.

The most important datum for the determination of the epicentre in No. 4 is the observation of the sea-quake on board the steamer Omrah at a point *long.* 104°50′E, *lat.* 21°27′S.

4. That the different phases of seismic movements have different directions may probably be best understood from the diagram of the earthquake No. 3. (see Pl. XXX.) In the seismogram, not only the commencement of the 1st prel. tremor (I), but also that of the 2nd one (II) and its successive waves (a-d) are larger in the NS than in the EW component, while this relation is quite contrary in the 1st princ. portion (III-D). It will also be seen that the 3rd phase of the princ. portion (V-γ) is enlarged in the NS component only. I have hardly any reason to assume such peculiarities as errors due to the instruments which are most reliable ones in our Institute, the pendulums of EW and NS components having 61.5 and 48.5 sec. as the periods of free vibration, and 15 and 20 times as the magnifications of their writing indices respectively. The same instruments registered both components in Nos. 4, 6 and 9, and NS component in No. 8. The other component in the last named earthquake is taken from the illustration given by Prof. Omori in the Publ. of the Imp. Earthq. Inv. Comm., No. 21, Appendix II. With respect to the diagrams of the four other earthquakes, the EW component in Nos. 1 and 5 was recorded by the instrument A, that in Nos. 2 and 7 by D and C respectively, while the NS component in Nos.

TABLE

Earth-quake No.	Compo-nent.	1st preliminary tremor.						2nd preliminary tremor.							
		I-a'	a'-b'	b'-c'	aver. mm.	Resultant dir.	amp.	II-a	a-b	b-c	c-d	d-e	aver. mm.	Resultant dir.	amp.
1	E-W W-E	Began gradually.				—	—	·15	·10	·10	·20		·14	S27° 4W	·30
	N-S S-N	Bagan abruptly.						·24	·17	·17	·49		·27		
2	E-W W-E	Began gradually.				—	—	·65	1·54	1·07	·48		·95	S41°·8E	1·42
	N-S S-N	Began very abruptly.						·75	1·20	1·50	·80		1·06		
3	E-W W-E	Began gradually.				—	—	·07	·07	·07	·07		·07	Due S	·67
	N-S S-N	Began abruptly.						·24	·75	1·05	·65		·67		
4	E-W W-E	Began gradually.				—	—	·17	·33	·33	·20		·26	S33° 7W	·47
	N-S S-N	Began gradually.						·20	·40	·56	·40		·39		
5	E-W W-E	Began gradually.				—	—	·40	·55				·48	N42°·0W	·72
	N-S S-N	Began gradually.						·40	·65				·53		
6	E-W W-E	·39	·54	·37	·43	N64°W	.48	·78	2·40	4·73	5·78	5·12	3·76	N53°·6W	4·68
	N-S S-N	·16	·25	·23	·21			·53	2·30	3·90	3·78	3·40	2·78		
7	E-W W-E	Began gradually.				—	—	·78	·78	·25	·78		·65	N3C°·8E	1·08
	N-S S-N	Beginning large.													
8	E-W W-E	Began gradually.				—	—	1·31	3·33	3·33	2·32		2·57	N46°·2E	3·57
	N-S S-N	Began gradually.						1·70	3·05	2·97	2·20		2·48		
9	E-W W-E	Began very gradually.				—	—	·67	2·60	4·66			2·64	N59°·9E	3·05
	N-S S-N	Began very gradually.						·65	1·75	2·19			1·53		

II.

1st principal portion.								3rd principal portion.						
III-A	A-B	B-C	C-D	D-E	aver.	Resultant		V-α	α-β	β-γ	γ-δ	aver.	Resultant	
mm.						dir.	amp.	mm.					dir.	amp.
3·2	5·4	5·0	2·7		4·1	N79°·4W	4·2							
·85	·68	·73	·79		·77									
1·78	3·3	2·9			2·6	N77·0°·E	2·7	·18	·71	·65	·36	·48	S25°·5E	1·12
·45	·84	·50			·60									
·53	1·30	2·73	1·33		1·60	N99°·2W	1·62	·28	·73	1·30		·77	N11°·2E	4·0
·08	·20	·35	·39		·26			3·1	4·9	3·7		3·9		
·22	·37	·37			·32	N64°·8W	·35	·13	·23	·15	·10	·15	S15°·0W	·58
·11	·13	·20			·15			·28	·51	·62	·73	·56		
·50	·60	·90	1·15	·95	·83	N19°·3E	2·44	8·2	10·2	8·05	8·5	8·74	N58°·5W	10·2
1·63	2·17	2·53	2·58	2·60	2·30			5·75	6·4	4·7	4·6	5·36		
1·25	1·00	·73	1·78		1·19	N17°·7E	3·93							
2·61	3·15	3·75	5·45		3·74									
1·70	2·20	1·65			1·85	N63°·1W	2·38							
·62	·98	1·22			·94									
·40	·33	·33	·36	·33	·35	N27°·5W	·76							
·70	·33	·20	·58	1·55	·67									
1·73	1·13				1·43	N35°·1W	2·48							
1·70	2·35				2·03									

1 and 7 was given by B, and in Nos. 2 and 5 by one whose magnification was 10 times, and whose period of free vibration was 30 sec.*

5. Table II shows the range of motion (double amplitudes) of the different phases together with the resultant directions and magnitudes. The numbers in the row E-W show the ranges of motion from *east to west*, and those in W-E the magnitudes in the opposite direction.

6. Table III gives the relation between the directions of the 2nd preliminary tremor (II), the 1st (III) and 3rd principal portions (V) and that of propagation. The deviation of directions with positive or negative sign means the angle through which the direction of movement deviated from that of the path in the counterclockwise or clockwise sense. As it will be seen from the average values, the directions of the 2nd preliminary tremor and the 3rd principal portion are almost coincident with the path, while that of the 1st principal portion is nearly normal to the latter.

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* For the details of the instruments, the reader is referred to Prof. Omori: Publ. of the Imp. Earthq. Inv. Comm. in Foreign Languages, No. 21.

TABLE III.

No.	δ		Direction.				Deviation of direction.			Range of motion.				
			J	II	III	V	II	III	V	II	III	V	III / II	V / II
										mm.	mm.	mm.		
1	42°	54′·6	S15°·5W	S27°·4W	N79°·4W	—	−11°·6	+95°·2	—	·30	4·3	—	14·0	—
2	59°	58′·6	S33°·8E	S41°·8E	N77°·0E	S25°·5E	+ 8°·0	+69°·2	− 8°·3	1·42	2·7	1·12	1·90	·79
3	48°	42′·4	S 1°·1W	S-N	N99°·2W	N11°·2E	+ 1°·1	+100°·3	−10°·1	·67	1·62	4·0	2·42	6·0
4	66°	1′·8	S35°·7W	S33°·7W	N64°·8W	S15°·0W	− 2°·0	+100°·5	−20°·7	·47	·35	·58	·74	1·23
5	50°	20′·1	N65°·1W	N42°·0W	N19°·3E	N58°·5W	−23°·1	+95°·1	− 6°·6	·72	2·44	10·2	3·40	14·2
6	51°	26′·4	N75°·1W	N53°·6W	N17°·7E	—	−21°·5	+87°·2	—	4·68	3·93	—	·34	—
7	54°	57′·2	N37° 0E	N36°·8E	N63°·1W	—	+ 0°·2	+100°·1	—	1·08	2·38	—	2·21	—
8	73°	39′·3	N54°·2E	N46°·2E	N27°·5W	—	+ 8°·0	+81°·7	—	3·57	·76	—	·21	—
9	125°	26′·7	N50° 0E	N59°·9E	N35°·1W	—	− 9°·9	+85°·1	—	3·05	2·48		·81	—
Average.							− 5°·6	+90°·5	−11°.4	1·77	2·32	3·98	2·95	5.56

7. The result contained in the foregoing § § may be summarized as follows:—

(*a*) The direction of the 1st prel. tremor, when it is distinct, tends to coincide with that of the path.

(*b*) The 2nd prel. tremor, whose direction coincides with the path, may possibly consist of longitudinal waves.

(*c*) The 1st princ. portion, whose direction is normal to the path, may possibly consist of transverse waves.

(*d*) The paths of the two last mentioned phases are probably common, as there are rocks of older geological formation giving as much transit velocities for the seismic waves of longitudinal and transverse types as the 2nd prel. tremor and the 1st princ. portion.

(*e*) Of the magnitude of the different phases, the 3rd princ. portion is the largest, but no definite relation could be found for the two other phases. In fact, the 2nd prel. tremor was larger than the 1st princ. portion in the earthquakes nos. 4, 6, 8 and 9 which had more distant origins, while this relation was quite contrary in the case of the nearer earthquakes.

(*f*) Similarity of the seismic motion originating at neighboring centres* is probably due to the existence of definite directions for the different phases and similarity of the path. With respect to the latter statement, the earthquakes of Group I, which were propagated along suboceanic paths, had the principal portion slightly developed in magnitude and duration when compared to the preliminary tremor, while those of Group II, mostly propagated along the free surface layer had well developed principal portion. This property, however, requires further investigation.

Jan. 1907. Seismological Institute, Tokyo.

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* See Prof. Omori: Publ. of the Imp. Earthq. Inv. Comm. No. 21.

On Earthquake Zones in Central Japan.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. Introductory. The four principal Japanese islands, namely, Hokkaido, Honshu (Main Island), Shikoku, and Kyushu, are arranged in a curvilinear form*, which may be divided into two portions, namely, the northern and southwestern halves, whose curvatures are turned in opposite directions; their convex sides facing towards SE and NW respectively. Omi, Iga, and the neighbouring provinces may be regarded as forming the junction between the two component arcs; and it is a noteworthy fact that we have just there great complications of topographical features, resulting in the formation of the Bays of Tsuruga and Ise, and the lake of Biwa. The latter, greatest of the sort in Japan, forms together with the Bay of Osaka a depression zone, whose direction is inclined at an angle of

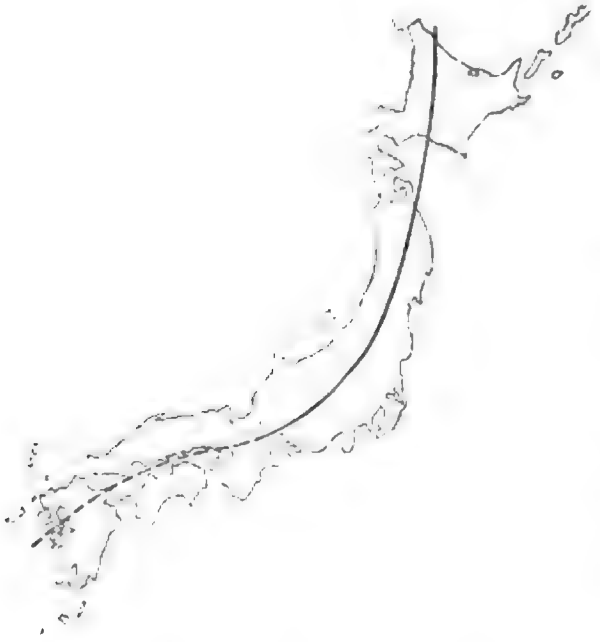

Fig. 1.

The curve shows the arcual form of the northern half of Japan, while the dotted line shows that of the south-western half.

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* See the *Bulletin*, No. 2.

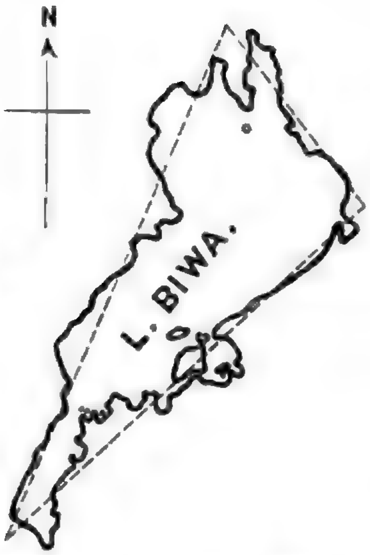

Fig. 2.
Showing the approximate form of the Lake Biwa.

45° to the central line or arc of the Japanese islands. As shown by the dotted line in Fig. 2, the Lake of Biwa is roughly triangular in form, and it is the object of the present note to see, if any, the relation among the earthquake zones in Central Japan with reference to the lake.

2. *Zones of Destructive Earthquakes in Central Japan.*

Great destructive earthquakes in Central Japan, whose origins can be more or less accurately ascertained, are the 5 following:—

(i)	Eqke of the	1st	year of	Keichō	:	Sept. 4, 1596.*
(ii)	,, ,,	2nd	,,	Kwanbun	:	June 16, 1662.
(iii)	,, ,,	1st	,,	Tempō	:	Aug. 19, 1830.
(iv)	,, ,,	1st	,,	Ansei	:	July 9, 1854.
(v)	Mino-Owari			Eqke	:	Oct. 28, 1891.

The Keichō earthquake (No. i), which was very violent and became famous from the destruction of the great Fushimi Castle erected by Taikō (Toyotomi Hideyoshi), had its origin in the district extending from the southern part of Kyōto to the towns of Fushimi and Yodo. On the other hand, the Kwanbun earthquake (No. ii), which was very violent and extensive in area, originated about 40 km to the NNE of the first earthquake, namely, to the west of Mount Hira, at the boundary of the northern part of

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* Prior to this date there were several destructive earthquake in Kyoto and the vicinity, the earliest great shock having occurred in 827. It is, however, impossible to locate exactly their origins.

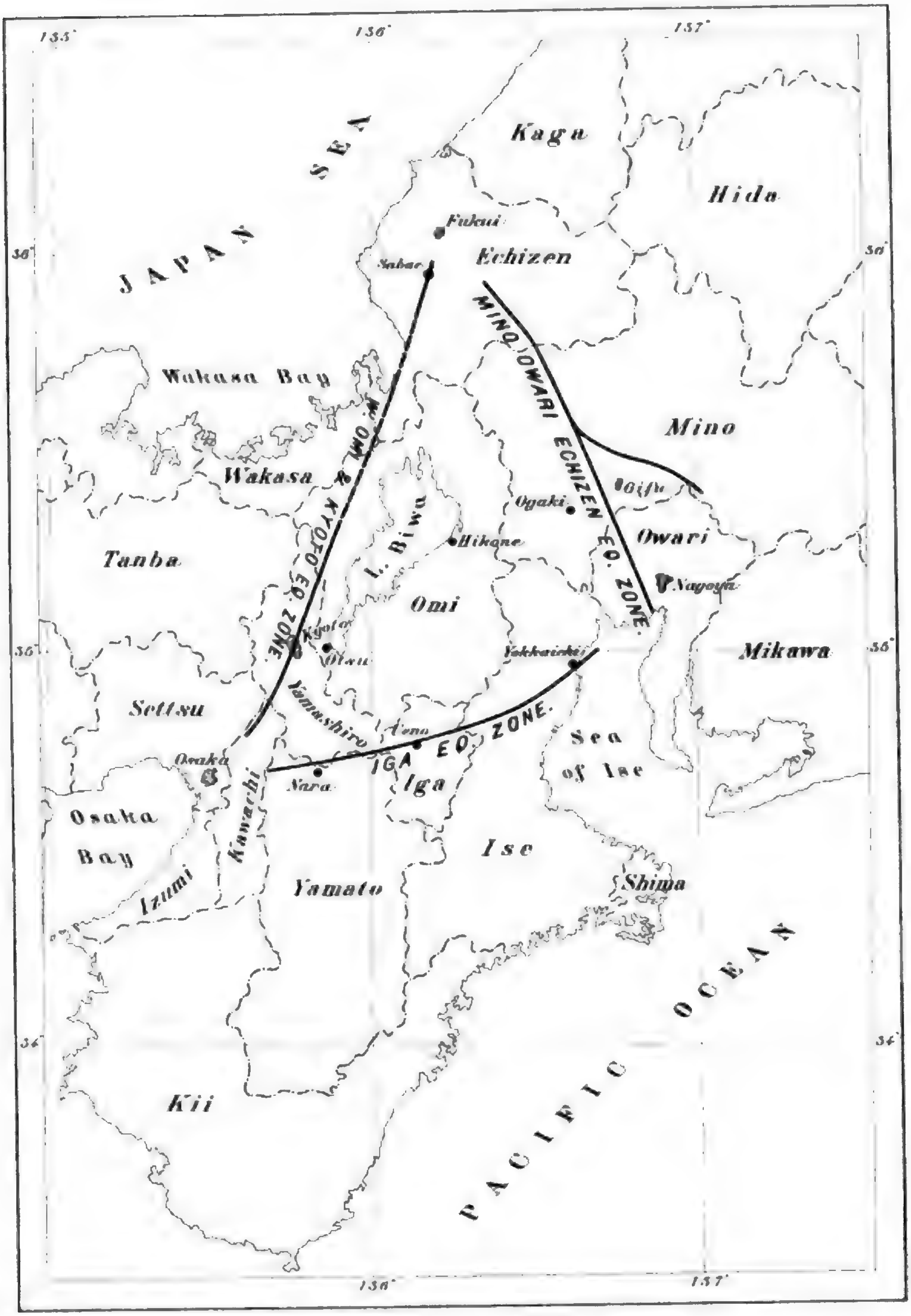
Fig. 3. Earthquake Zones in Central Japan.

- - - - - - Boundary of provinces.

W. Omi and Kyoto EQ. Zone .... (*A*).

Iga EQ. Zone .... (*B*).

Mino Owari Echizen EQ. Zone .... (*C*).


135°
136°
137°
36°
35°
34°
JAPAN SEA
Kaga
Hida
Fukui
Sabae
Echizen
Wakasa Bay
Wakasa
W. OMI & KYOTO EQ. ZONE
MINO OWARI ECHIZEN EQ. ZONE
Mino
Gifu
Ogaki
Owari
Hikone
L. Biwa
Tanba
Omi
Nagoya
Kyoto
Otsu
Yokkaichi
Mikawa
Settsu
Yamashiro
Ueno
IGA EQ. ZONE
Sea of Ise
Osaka
Nara
Iga
Kawachi
Osaka Bay
Izumi
Ise
Yamato
Shima
PACIFIC OCEAN
Kii

the province of Yamashiro and the western part of the province of Ōmi. The Tempō earthquake (No. iii), which was smaller than the Keichō and Kwanbun shocks, originated between the centres of the two latter, being strongest in the northern part of Kyōto and the adjacent region to the north. Thus, it will be observed that the three earthquakes above mentioned all originated along a line which extends from the western part of Ōmi to the vicinity of Ōsaka, in the direction of N20°E and S20°W. This earthquake zone, which may be called ***A***-Zone, (Fig. 3), passes on the north through the city of Fukui (province of Echizen); it being specially interesting that the severe earthquake of March 22, 1900, which was felt strongly in the vicinity of the town of Sabaé (Echizen), originated just on the northern prolongation of the zone under consideration. It will be seen that the occurrence of the different earthquakes along ***A*** was in accordance with the principle explained in the next Article.

The Ansei earthquake* (No. iv) was a very extensive shock and was most violent about the city of Uéno (province of Iga), the epifocus, ***B***-Zone (Fig. 3), being a zone about 100 km in length, which extends in a mean direction of S70°W—N70°E from the vicinity of the city of Nara (province of Yamato) to that of the city of Yokkaichi (province of Ise). The western end of this zone also points to the city of Ōsaka, on the head of the Ōsaka Bay.

Finally, the great Mino-Owari earthquake was caused by tectonic disturbances which produced faults extending from the central part of the province of Echizen to the south-eastern part of the province of Mino, the vertical and horizontal convulsions of the ground being most markedly manifested in the famous Néo-Valley of the latter province. There was very probably an underground line of disturbance which formed a direct southern prolongation of the Néo-Valley fault, reaching down to the head of the Bay of Ise. On the whole, the direction of the epifocus, **C**-Zone, (Fig. 3), of the Mino-Owari earthquake was N 20° W —S 20° E.

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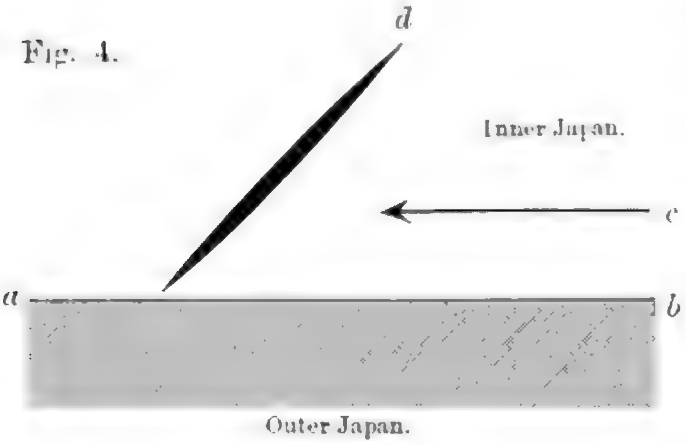
* This is different from the two great earthquakes, also in the 1st year of Ansei, which originated off the south-western coast of Japan, respectively on the 23rd and 24th, Dec. 1854.

The three earthquake zones, **A**, **B**, and **C**, form approximately a right-angled triangle, whose hypothenuse is **A**, and whose right angle is formed by **B** and **C**, these two latter sides being inclined to the former at an angle of 45° or 50.° The great destructive earthquakes in the central part of Japan seem always to originate at some parts of the sides of this seismic triangle, which is roughly similar to, and similarly situated as, the triangle formed by the Lake Biwa. It thus appears probable that the latter was formed as the result of the existence of some forces in the earth's crust in this part of Japan. The zones **B** and **C** may be regarded as being respectively *parallel* and *normal* to the general arc or central line of the Japanese islands.

Fig. 4.



The formation of the zone **A** may be explained by the application of the theory of the *secondary*, or *shear*, cracks accompanying the fault produced in the epifocal zone of a destructive earthquake.* Thus let *ab* (Fig. 4) represent the boundary between the convex, or outer, side and the concave, or inner side, of the Japan arc. If now the latter side be sheared relatively to the former as shown by the arrow *c*, then there ought to be produced some oblique cracks, as *d*, which is inclined to the boundary line, *a b*, at an angle of 45°. *d* corresponds to the seismic zone **A** or the depression formed by the Biwa Lake and the Osaka Bay. That some such action of the terrestrial forces as above imagined took place seems probable, since the geological formations on the exterior or convex side of the Japan arc are regular in arrangement, while those on the inner or concave side are very irregular and complicated.

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* See the *Bulletin*, No. 1.

Recent Strong Earthquakes in the Shinano-gawa Valley (Central Japan).

By

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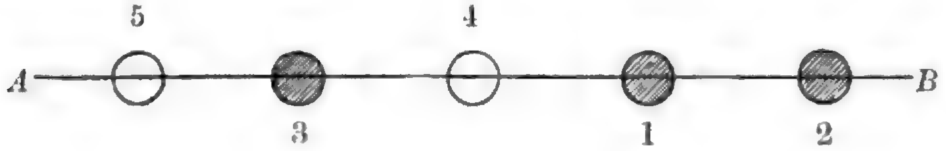
Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** Destructive earthquakes, whether great or local, are generally not isolated phenomena, but form groups each of which happen along a seismic zone of greater or less extent; no two violent shocks occurring successively at one and the same place. Thus let A B (Fig. 1) represent a seismic zone; 1, 2, 3, 4 and 5 being different earthquake centres. If now the first two earthquakes took place at 1 and 2 respectively and the 3rd one at 3, the next shock may be expected to occur somewhere at 4. Again, after the occurrence of the earthquakes 1...4, the 5th one may be expected to happen towards either end of the zone under consideration, say at 5.

Fig. 1.



2. ***Strong Earthquakes in the Shinano-gawa Valley.*** The case diagrammatically illustrated in Fig. 1 has exactly been verified by the 5 strong earthquakes, which happened, between the years 1886 and 1899, in the Shinano-gawa valley; the latter forming one of the active seismic zones in the central part of the Main-Island.* The dates of these 5 earthquakes are as follows:—

No. 1. July 23, 1886 ; 1.00 A.M.
,, 2. July 22, 1887 ; 8.30 P.M.
,, 3. Jan. 7, 1890 ; 3.43 P.M.
,, 4. Jan. 17, 1897 ; 5.36 A.M.
,, 5. Jan. 22, 1899 ; 8.04 A.M.

It may by the way be noted that the first two earthquakes occurred at an almost identical epoch of the year, namely, on 23rd and 22nd of July, while the three remaining ones occurred all in July. This is one of the instances, in which strong or destructive earthquakes belonging to a given seismic zone tend to occur at nearly the same hour in the day, or in the same month of the year. The approximate positions of the epicentres of the 5 earthquakes are indicated in Fig. 2 by the numerals 1, 2, 3, 4, and 5 respectively.

Eqke No. 1 originated at the boundary of the two provinces of Echigo and Shinano, and was strongly felt in the counties of Higashi-Kubiki (Echigo) and Midochi (Shinano), causing a destruction of one house, besides several cases of damage to *dozo* (Japanese ware houses), *ishigaki* (stone retaining walls), etc. Some cracks of the ground were also produced.

Eqke No. 2 originated in the Koshi county, (province of Echigo), where the ground was cracked and water and sand were ejected; some temples being displaced 2 to 6 inches on their foundations, and one person wounded. The shock was also strongly felt in the two counties of Mishima and Minami-Kanbara (Echigo).

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* This is the zone marked M in my paper on the Distribution of Recent Japan Earthquakes. The *Bulletin*, No. 2.

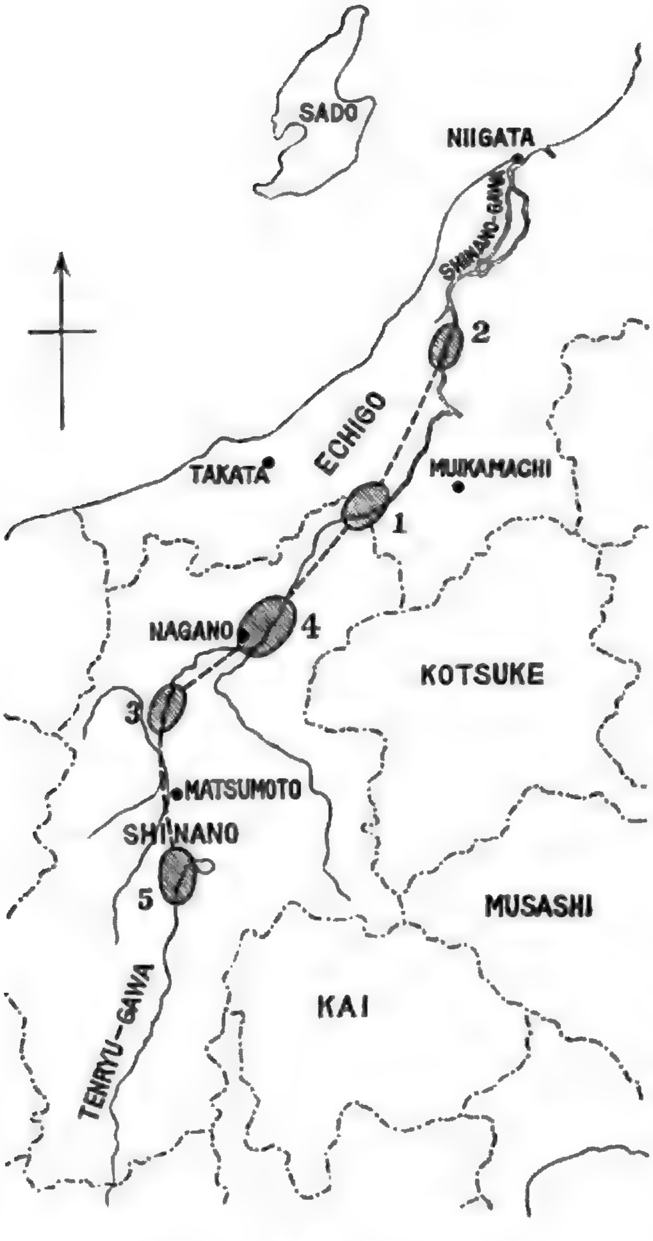
SADO
NIIGATA
SHINANO-GAWA
2
ECHIGO
TAKATA
MUIKAMACHI
1
NAGANO
4
KOTSUKE
3
MATSUMOTO
SHINANO
5
MUSASHI
KAI
TENRYU-GAWA

Fig. 2.

Map illustrating the Shinano-gawa Eq. Zone. Small shaded ellipses indicate the approximate positions of the Eq. Origins

Eqke No. 3 was most severely felt in the counties of Kami-Midochi, Higashi-Chikuma, Kita-Atsumi, and Sarashina (all in the province of Shinano). Houses and *dozos* were damaged, cliffs and roads were cracked, tomb stones were overturned, water and sand were ejected from ground cracks.

Eqke No. 4 was severely felt in an area of about 60 square miles in the two counties of Kami-Takai and Kami-Midochi (in the province of Shinano). The seismic damage was nearly the same as in Eqke No. 3, the epicentre being probably situated on the eastern side of the Shinano-*gawa*.

Eqke No. 5 was strongly felt in the counties of Suwa, Kami Ina, and Higashi-Chikuma (in the province of Shinano), the centre of disturbance being in the vicinity of Lake Suwa. In this case, the motion was not so intense as in the four preceding shocks, due probably to a greater depth of its origin.

Summary. It will be observed that the 5 earthquakes above described were each a local severe shock, whose damge was limited to cracks of the ground, some injury to buildings, and the like. Further, (2) originated about 33 miles to the NNE of (1), while (3) originated at a greater distance in the opposite direction, at 50 miles to the SW of (1), namely, a little distance to the SE of the town of Ōmachi. Thus it was very likely that the next place to be visited by a strong shock was between (1) and (3). This has been fulfilled by the occurrence of the next earthquake at (4) or the vicinity of the city of Nagano. The famous great earthquake of Zenkōji on May 11, 1844, was of the same character as, but much more violent than, Eqke No. 4.

The occurrence of Eqke No. 5 further southwards was in accordance with the natural order of things to be expected.

3. *Seismic Activity in America, Asia and Europe.* The successive occurrence in recent years of a number of destructive earthquakes along the American and Mediterranean-Himalayan seismic zones* furnish another illustration of the principle explained in § 1, manifested in a grand scale.

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* See the *Bulletins*, Nos. 1 and 2.

Note on the Eruptions of the Unsen-daké in the 4th year of Kansei (1792).

By

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The eruptions in the 4th year of Kansei (1792) of the Unsen-daké which stands on the peninsula of Shimabara, in the province of Hizen (Kyushu), extended over a period of nearly 4 months. They were preceded, for several weeks, by a number of small shocks, which caused some landslips from mountain slopes; the first eruption having taken place on Feb. 12, 1792, at midnight, near the top of the Fuken-san (1478m above the sea level), one of the highest peaks of the mountain. Subsequently there were several eruptions from different neighbouring places, attended by numerous detonations and earthquake shocks. Of the latter, those on April 21st and 22nd (March 1st and 2nd, Lunar Calendar) were the strongest, causing in the town of Shimabara some damage to buildings and cracks of the ground about 1 inch in width. The final catastrophe occurred at about 6 o'clock in the evening of May 21st, (April 1st, Lunar Calendar), when two violent earthquake shocks took place, and the entire southern slope of the Mae-yama (876m above sea level), which is opposite the town of Shimabara, slipped down, producing an immense avalanch of rocks and earth. The latter quickly descended into the sea of Ariaké, which separates the Peninsula from the province of Higo, causing a considerable change in the topography of the harbour. Amongst others, three small islands were wiped out of existence, and several dozen others newly created. Simultaneously with the landslip, great sea waves were formed, which rolled in along the shore and attained at some places a height of 20 to 30 feet, causing devastations among 17 villages along the eastern coast of the Peninsula for a distance of 77 km. The number of the casualties on this side of the Ariaké Sea amounted to 9,745 persons killed and 707 persons wounded, besides 496 cattle and horses. The sea waves produced also a considerable amount of damage on the eastern shores of the Ariaké Sea, namely, in the counties of Akita, Udo, and Tamana, of the province of Higo, where the total number of persons killed amounted to 5,100. Along the coasts of the Amakusa Islands, 343 people were drowned. Earthquake shocks continued to happen for the next two months.

The local earthquakes which accompanied or preceded the eruptions of the Unsen-daké were not very destructive, but much severer than is usually the case with volcanic *explosions*. In these latter cases, as with the recent outbursts of Japanese volcanoes, namely, Bandai-san (1889), Azuma-san (1893), Adataro-san (1900), and Tori-shima (1902), the phenomenon is purely that of a steam explosion, and the volcanic force is mainly spent in blowing and projecting mountain masses, only a small amount of the energy being transformed into earthquake vibrations On the other hand, in eruptions like those of the Unsen-daké, which were attended by no gigantic explosion, the subterranean volcanic energy would be in a great measure spent in causing mechanical vibrations, resulting in comparatively severe earthquake shocks.

The cause of the great Shimabara sea waves seems to have been the disturbances of the waters by the enormous quantity of rock and earth masses thrown into latter. Thus the volume of the *debris* was roughly 0.55 cubic km, or equivalent to an area of 550 square km, with a thickness of 1 metre. Such an area is nearly equal to that of the Ariaké Sea, which is an inland body of water included between the two provinces of Hizen and Higo, and the volume of the *debris* thrown suddenly into the sea seems to be sufficient to produce an initial displacement of the surrounding water masses, the disturbances thereby created being propagated to the different parts of the shores, where tidal waves were formed. The great landslips from the Mae-yama was evidently the effect of the local but violent earthquake shocks.

Instances exactly similar to the Unsen-daké eruptions are not rare. Thus, the eruption in 1868 of Mauna Loa, in the Island of Hawaii, began on March 27 of that year. On April 2, there took place a severe earthquake shock, which did some damage to buildings in the vicinity, causing at the same time, a landslip of an enormous quantity of soft clay from the head of a ravine called Kapapala at the south-eastern flank of the mountain. This produced a mud stream, half a mile in width and about 30 ft. in depth at the centre, which descended into the sea in the interval of only a few minutes, over a distance of 3 miles. The result was the immediate formation of large sea waves, which rolled in along the shore of Kau district, attaining a height of 40 to 50 feet.

The sea waves attending the great eruptions of Krakatoa in 1883 were also probably caused in a measure by the ejection of the rock masses into the surrounding sea waters.

Seismograms Showing no Preliminary Tremor.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** The examination of the horizontal pendulum diagrams of the Japan earthquake of Jan. 21, 1906, which originated off the south-eastern coast of the Main Island, has accidentally revealed that some earthquake motion indicates no preliminary tremor when observed at places situated in certain directions relative to the seismic origin; the earthquake of Feb. 6, 1907, also indicating the same fact. Studies in this connection may throw much light on the nature of the vibrations composing the initial part of the *macro-seismic* earthquake motion; the present note giving a short account of the observations of the earthquake of Jan. 21, 1906. I have here to express my thanks to Mr. N. Shimono, Director of the Ōsaka Meteorological Observatory, for his valuable suggestions and assistance given me in connection with the investigation of the earthquake in question.

2. ***Isoseismals.*** (Fig. 1.) The earthquake was felt as a slight or moderate shock over a considerable area, which extended from the south-eastern portion of Hokkaido on the north-east to the strait between the islands of Shikoku and Kyushu on the south-west; the boundary of this area, or the isoseismal ***I***, being symmetrical with respect to a line, which is normal to the Japan arc and connects the cape Inuboé (province of Shimosa) with the

southern end of the Sado island. The isoseismal line ***II*** includes the area within which the shock was *strongly* felt.

The earthquake was recorded by Omori Horizontal Pendulums at the different stations in Japan and also at the Meteorological Observatory of Zikawei, near Shanghai.

3. ***Position of the Origin.*** The approximate position of the earthquake origin may be inferred from the seismograms obtained at Tokyo, Mount Tsukuba, Mito, and Miyako (province of Rikuchu), where the preliminary tremor was clearly observed, as follows.

Place.	Duration of 1st Prel. Tremor $=y$.	Epicentral Distance (*Calculated*) $=x$
Tōkyo	43 *sec.*	350 *km*
Mt. Tsukuba	43	350
Mito	47	380
Miyako	78	610

The epicentral distances given in the above table have been calculated by the formula*

$$x^{km}=7.27\ y^{sec.}+38^{km}.$$

The 4 circles drawn about Tokyo, Mt. Tsukuba, Mito, and Miyako, as centres with the corresponding calculated values of the epicentral distances for the radii, meet as shown in Fig. 1 at points which are close to one another. The approximate position of the earthquake origin thus determined is

$$\varphi=34^\circ\ 23'\text{N},\qquad \lambda=143^\circ\ 26'\text{E}\ ;$$

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* The *Publications*, No. 13.

the actual arcual distances from the epicentre, the time* ($=t_1$) of earthquake occurrence, and the duration ($=y$) of the preliminary tremor, for the different stations being as follows.†

Place.	Epicentral Distance $=x$.	Time of occurrence $=t_1$	Duration of Prel. Tremor $=y$
Tōkyo	3° 17′=365 *km*	10ʰ 50ᵐ 31ˢ P.M.	43 *sec.*
Mt. Tsukuba ...	3 18 =367	10 51 15	43
Mito	3 09 =350	10 50 33	47
Mizusawa	5 06 =567	10 51 45	67
Miyako	5 23 =598	10 52 44 (?)	78
Ishinomaki	4 23 =487	———	
Osaka	6 32 =726	10 50 28	0
Kyōto	6 21 =705	———	0
Kōbe	6 49 =758	10 50 30	0
Tadotsu	8 00 =889	10 50 23	0
Shanghai	18 57 =2106	10 52 15	141
Taihoku	21 10 =2352	10 53 20	180
Taichū...	22 15 =2472	10 52 12 (?)	177
Hōkoto	23 27 =2606	10 51 15 (?)	202
Manila...	28 20 =3148	10 54 23	281 (?)

4. ***Character of the Seismograms.*** The seismograms at the different stations are shown in Figs. 2—15, as follows.

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[*] The times are given in the 1st Normal Japan Time, or that of longitude 135° E.

[†] All the observation made with Omori Hor. Pendulum, except that at Manila which was made with Vicentini Seismograph.

No. of Fig.	Station.	Component.	Multiplication.	Pendulum Period.
2	Ōsaka	EW	20	27 sec.
3	„ (slow time rate)...	„	10	30
4	Kyōto	„	20	30
5	Kōbe	NS	20	25
6	Ishinomaki	EW	11	25
7	Tōkyo (Hitotsubashi)	„	10	24
8	„ (Hongō)	„	120	26.5
9	„ „	NS	20	48.5
10	„ „	EW	15	61.5
11	„ „	Vertical	30	2.0
12	„ „	„	12	4.5
13	Taihoku (Formosa) ...	EW	10	23
14	Mito	„	20	28.8
15	Miyako	„	120	18

From Figs. 2—15, it will be observed that the seismograms obtained at Tōkyo, Mito, Miyako, Ishinomaki, and Taihoku,* indicates the preliminary tremor in the usual way, while those obtained at Ōsaka (EW) and Kyōto (EW) has no preliminary tremor at all. In the Kōbe seismogram (NS), the motion was quite large at the very commencement as was the case with the two last-mentioned places; there being, however, an ill-defined indication of the preliminary tremor.

I give next a short description of the seismograms obtained at the three stations of Ōsaka, Kōbe, and Taihoku: *a*, 2*a*, and

---

[*] The seismograms obtained at Mt. Tsukuba, Mizusawa, Shanghai, Taichu, Hōkoto, etc. also indicated the preliminary tremor.

T denoting as usual the amplitude, double-amplitude, and the complete period of vibration, respectively.

Osaka. (Fig. 2.) EW component (Multiplication = 20). Natural oscillation period of the horizontal pendulum=27 sec. The earthquake began quite suddenly with a large quick displacement of 2.9 mm. towards W, followed by a counter motion of 4.9 mm. towards E, this latter being the absolute maximum. The vibrations were active for 2ᵐ 20ˢ, being composed of the following 3 sets:—

$T=$ 3.7 sec. (larger vibrations),
$T=$ 5.7 „ (smaller „).
$T=27.0$ „ $2a=6.5$ mm (pend. oscillations).

The motion was distinct for further 5ᵐ 15ˢ:—$T=4.9$ sec.

The diagram furnished by a horizontal pendulum apparatus, whose recording drum rotated once in 24 hours, (Fig. 3), also indicated no preliminary tremor.

Kobe. (Fig. 4.) NS component (Multiplication=20). Natural oscillation period of the horizontal pendulum=25 sec. The earthquake began suddenly with a large vibration, of $T=36$ sec. whose two displacements were as follows:—

1st .... $a=1.3$ mm, towards N,
2nd.........$2a=1.7$ „ „ „ S;

the latter being the maximum of this sort of motion.

The motion was most active for the first 3ᵐ 15ˢ and consisted of the following 3 sets of vibrations:—

$T=$ 3.1 sec.
$T=11.1$ sec., $2a=2.1$ mm (this max. occurred 38 sec. after the commencement).
$T=24.5$ sec., $2a=3.3$ mm (pend. oscil.)

Thereafter the motion gradually diminished, the movements being as follows:—

$$\begin{cases} T=11.3 \text{ sec.}, & 2a=0.58 \text{ mm} \\ T=\ 4.0\ \ ,,\ (?), & 2a=\text{small.} \end{cases}$$

Towards the end:—$T=11.1$ sec.

Taihoku. (Fig. 13.) EW Component (Multiplication=10). Natural oscillation period of the horizontal pendulum=23 sec.

The preliminary tremor lasted $3^m\ 0^s$, the movements at the very commencement being as follows:—

1st .... $a=0.11$ mm, towards W;
2nd ....$2a=0.19$,, , ,, E.

The average periods were:—$T=4.0$ sec., $T=2.1$ sec.

The principal portion lasted $6^m\ 55^s$, the movements at the commencement being as follows:—

$$\begin{cases} \text{1st} \ldots\ldots\ldots & a=0.65 \text{ mm, towards W;} \\ \text{2nd} \ldots\ldots\ldots & 2a=2.55\ \ ,,\ ,\ \ \ ,,\ \ \ \text{E;} \\ \text{3rd} \ldots\ldots\ldots & 2a=2.40\ \ ,,\ ,\ \ \ ,,\ \ \ \text{W.} \end{cases}$$

The subsequent motion was much smaller.

5. *Vibration at the Commencement of the Earthquake.*

(i) *Observations at Ōsaka, Kōbe, Kyōto and Tadotsu.* The 1st vibration of the earthquake motion recorded at the 4 stations of Ōsaka, Kōbe, Kyōto, and Tadotsu, which are situated westwards from the origin, and where the preliminary tremor was entirely absent or unduly large, was as follows:—

Station.	1st Displacement.	2nd Displacement.	Remarks.
Ōsaka (EW).	mm 2.88, towards W.	mm 4.88, towards E.	Quick vib. This was the abs. max.
Kōbe (NS).	1.23 ,, N.	1.78 ,, S.	Quick vibration.
Kyōto (EW)	1.75 ,, W.	2.68 ,, E.	Slow vib. mixed with quick movements.
Tadotsu (EW).	0.90 ,, W.	2.00 ,, E.	Slow vibration.

Combining the observations at Ōsaka and Kōbe, which are near to each other, we find the following resultant motion:—

1st displacement......... $a=3.08$ mm, towards N 67° W.
2nd „ ......$2a=5.14$ „ , „ S 71° E.

As the earthquake origin lies to the S 80° E of Ōsaka the initial vibration may be regarded as due to the *longitudinal wave*, and took place in a direction parallel to the line joining the places of observation with the centre of disturbance ; the 1st displacement being directed away from the latter. The initial displacement in the E W component at Kyōto and Tadotsu was also directed towards W. It may be here noted that some microseismographs with a large multiplication ratio and a short natural oscillation period, say, of 2 or 3 seconds, are, on the occasion of a sharp local shock or large earthquake, usually thrown at once into big proper oscillations, thereby indicating apparently or *diagrammatically* the maxmium movement at the commencement. With the observations at Ōsaka and Kōbe, however, the movements recorded were really those of the ground, their periods being the same at the two places, namely, 3.7 and 3.6 sec., and quite different from the natural oscillation periods of the horizontal pendulums, which were 27 and 25 sec. respectively.

(ii) *Observation at Tōkyo.* The observation at Tōkyo, where the preliminary tremor, was clearly indicated is also very interesting, as it gives the directions of vibrations at the very commencement of the motion, and of the principal portion. Taking suitably the mean value of the EW component motion, we find:—

1st displacement at the commencement of the preliminary tremor............$a=0.60$ mm, towards W ;

the simultaneous NS and vertical components being as follows:—

$$\begin{cases} a=1.05 \text{ mm, towards S,} \\ a=0.54 \text{ „ , downwards.} \end{cases}$$

These give for the resultant horizontal motion the following:—

initial (prel. tremor) displacement.........$a=1.2$ mm, towards S 30° W.

The counter horizontal motion was:—

$2a=3.2$ mm, towards N 22° E.

Taking the mean from the 1st and the counter displacements, we find:—

direction of the initial vibration.........S 26° W—N 26° E.

As now the origin of the earthquake was to the S 65° E of Tōkyo, it will be observed that the direction of motion of the vibration at the commencement of the preliminary tremor was exactly at right angles to the line joining Tōkyo with the origin; that is to say, the preliminary tremor *in this particular instance* belonged to the *transverse wave.*

Turning now our attention to the *principal portion,* we obtain the following mean result for the 1st displacement of the large vibration at the commencement:—

1st displacement...... . $a=9.9$ mm, towards N58°W.

The counter EW component motion was 13 mm towards E, the two displacements of the vertical motion being respectively $a=2.3$ mm downwards, and $2a=3.8$ mm upwards. The NS component pointer, however, unfortunately went out of the smoked paper and did not record the 2nd displacement and the subsequent movements. It will be observed that the 1st displacement of the principal portion was nearly parallel to the line joining the earthquake origin with Tōkyo, thus belonging to the *longitudinal wave.*

(iii) *EW Component Observations at Mito, Ishinomaki and Miyako.* The seismogram at Mito, which is situated about 100 km to the NW of Tōkyo, was similar in character to those obtained at the latter place. Thus we have:—

Mito (EW)
1st displacement at the commencement of the preliminary tremor=0.41 mm, towards W ;
1st displacement (a) at the commencement of the principal portion=5.4 mm, towards W.
2nd displacement $(2a)$, or the counter motion of the preceding=11.8 mm, towards E.

The directions of the movements at the commencement of the EW component principal portion obtained at Ishinomaki and Miyako, both situated in the north-eastern part of the Main Island, were the same as at Tōkyo, being directed towards W and towards E respectively.

6. Transverse and Longitudinal Vibrations. By comparing the observation at Tōkyo with those at Ōsaka and Kōbe, we arrive at the conclusion that the first vibrations in the preliminary tremor registered in the former place were due to the *transverse wave*, while the large principal vibrations at the very commencement of the earthquake motion registered at the two latter places (as well as Kyōto and Tadotsu) were due to the *longitudinal wave.* To explain these peculiar relations, we may suppose that the preliminary tremor consisted, from some cause, mainly of the transverse vibrations in a nearly N—S direction. Such movements would give the preliminary tremor at Tōkyo in nearly the N—S direction, but would be overtaken, along the path towards Ōsaka and Kōbe, by the longitudinal wave, whose propagation velocity is greater than that of the transverse wave; the result being that at the last mentioned places we got first the large vibrations constituting the principal portion, due to the longitudinal wave.

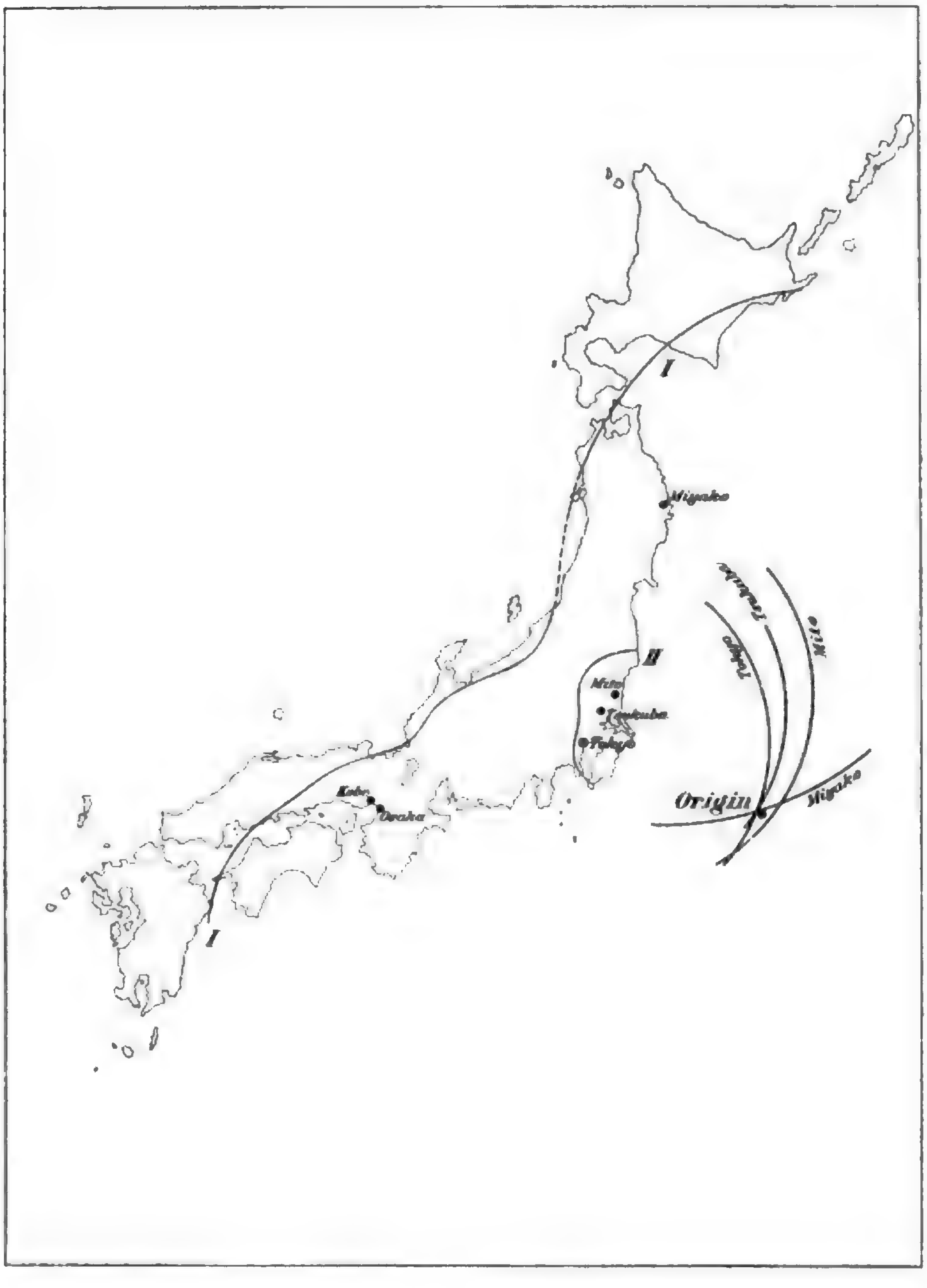
Google

PL. XXXII.

Fig. 1. Map of Japan, showing the Isoseismal Lines and the Position of the Origin of the Earthquake of Jan. 21, 1906.

(I) Boundary of the area of slight motion.

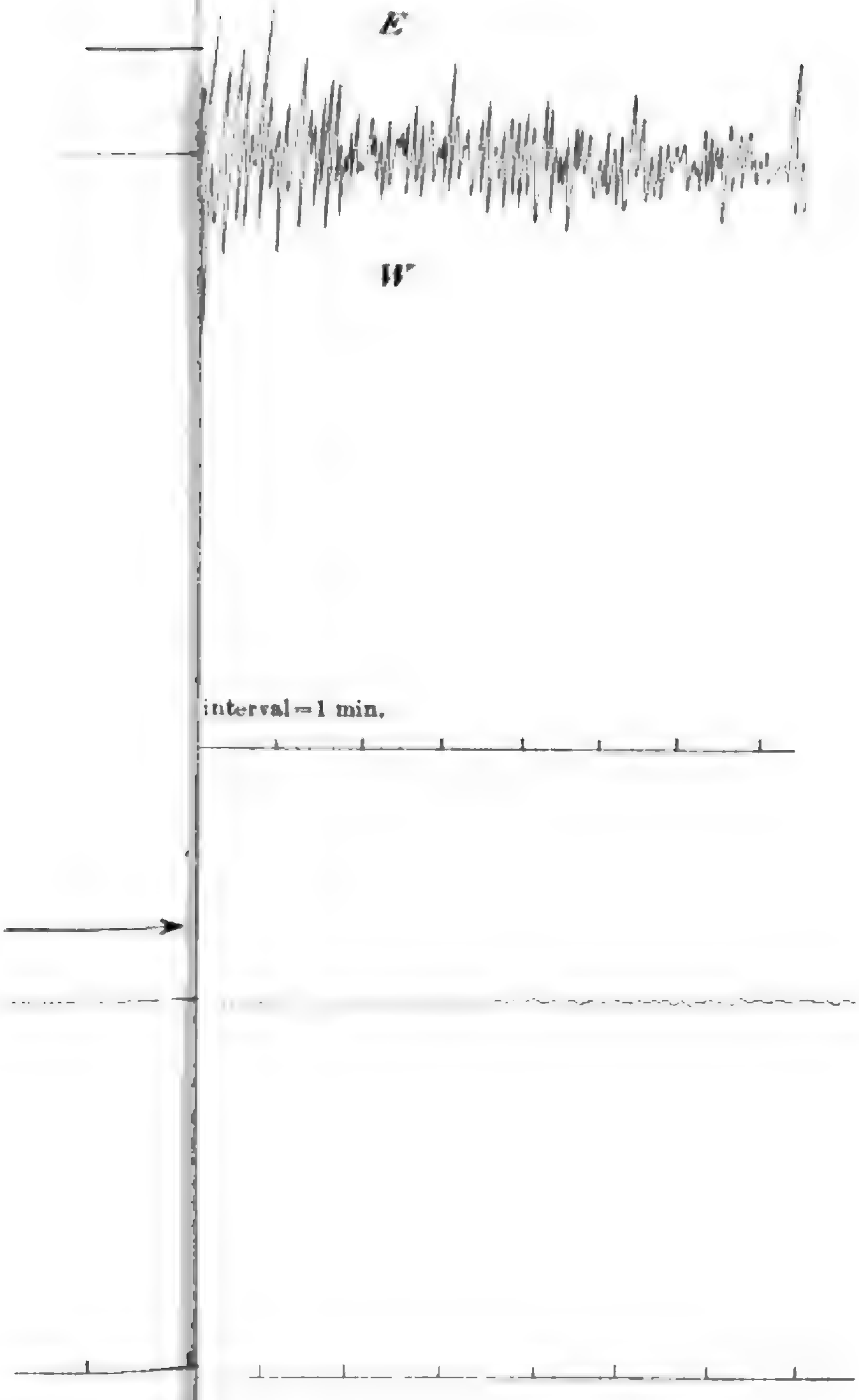
(II) „ „ „ „ of strong motion.


I
Miyako
II
Mito
Tsukuba
Tokyo
Tsukuba
Tokyo
Mito
Origin
Miyako
Kobe
Osaka
I

PL. XXXIII.

saka Observation.

nent. Multiplication = 20.



Earthquake of Jan. 21, 1906. PL. XXXIV.

a.........Commencement.

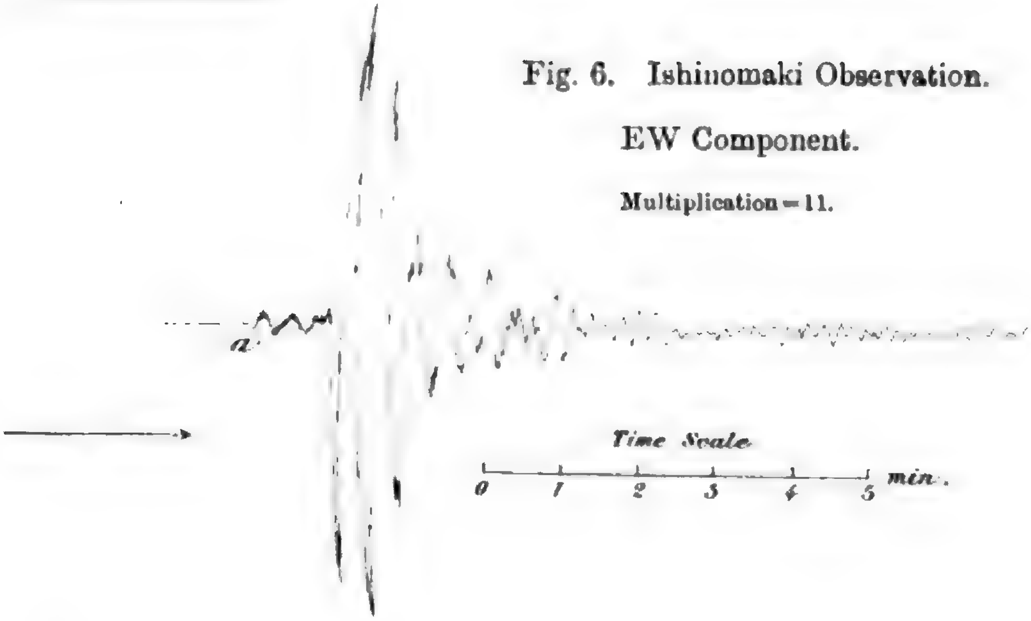


Fig. 6. Ishinomaki Observation.

EW Component.

Multiplication = 11.

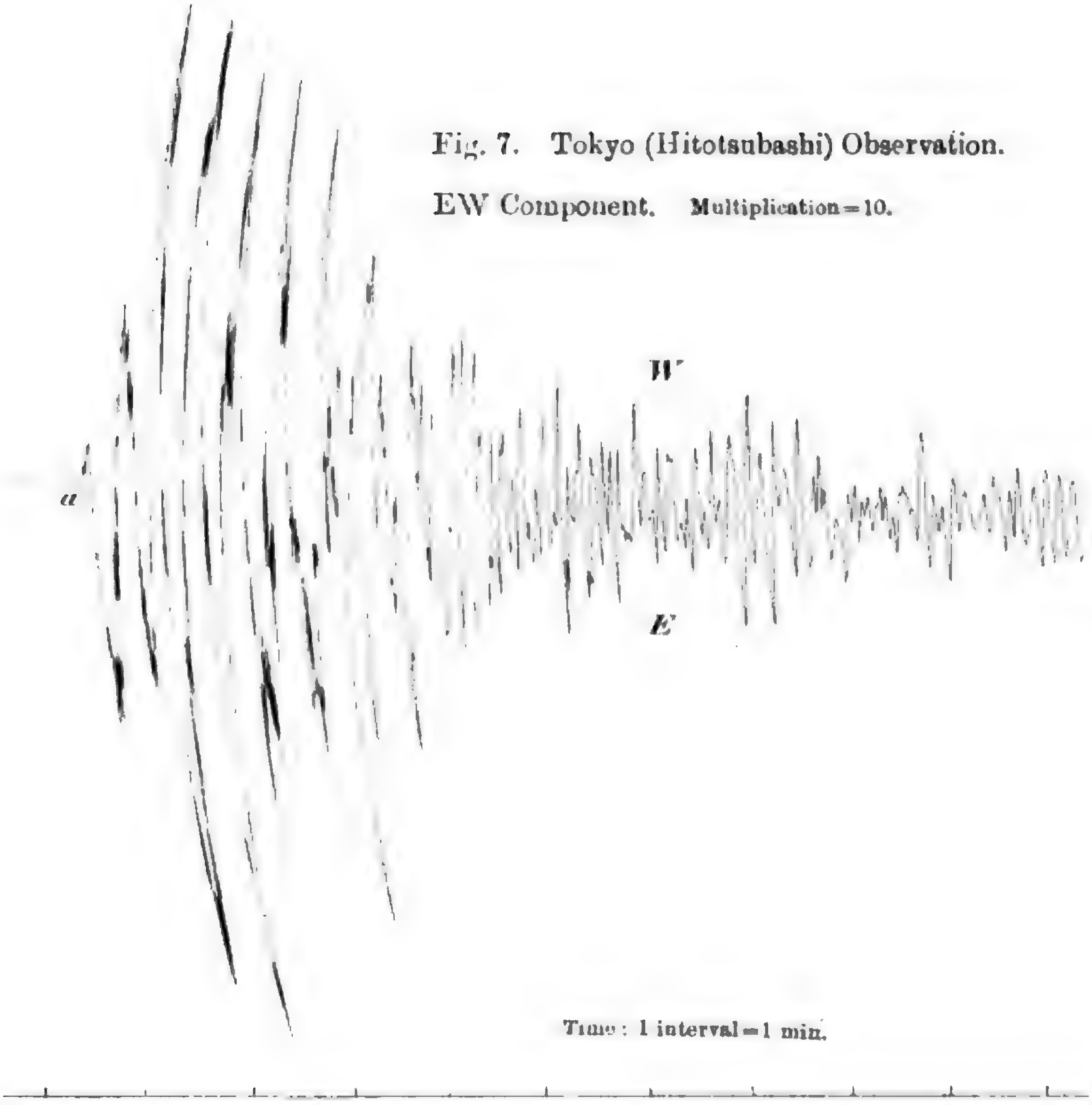


Fig. 7. Tokyo (Hitotsubashi) Observation.

EW Component. **Multiplication = 10.**

Time: 1 interval = 1 min.

PL. XXXV.

Earthquake of Jan. 21, 1906.

Observation in Tokyo (Hongo).

Time : 1 interval = 1 min.

a.........Commencement.

(×) *Pointer went out.*

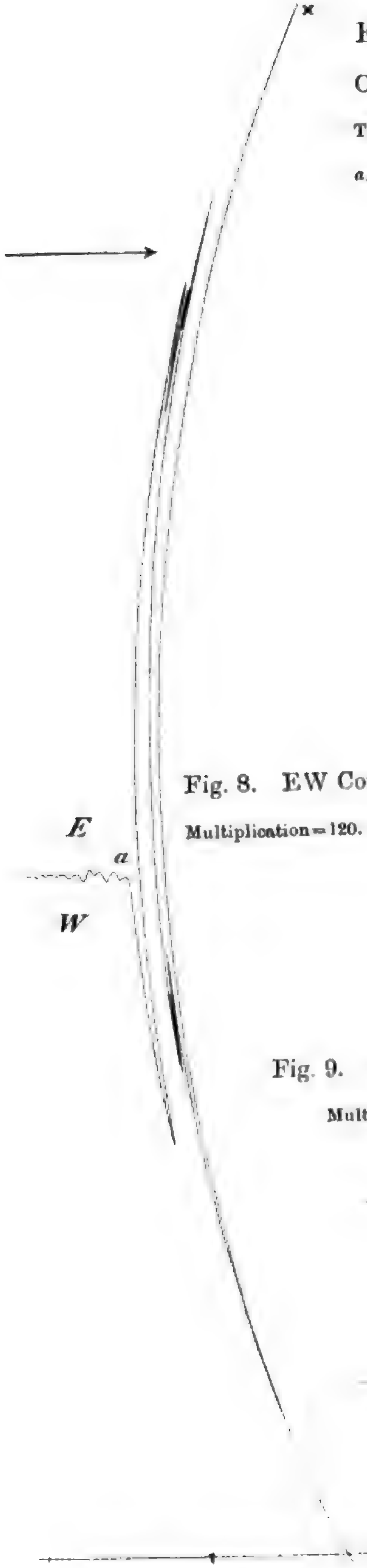


Fig. 8. EW Component.

Multiplication = 120.

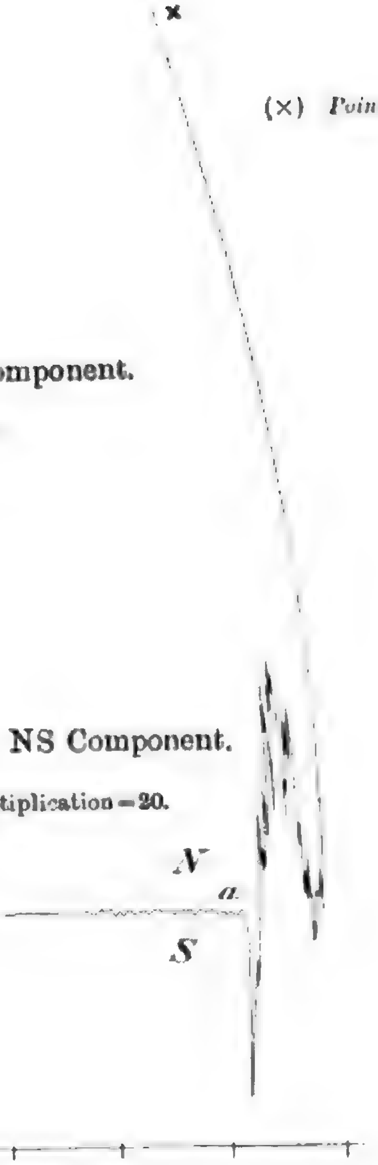


Fig. 9. NS Component.

Multiplication = 20.

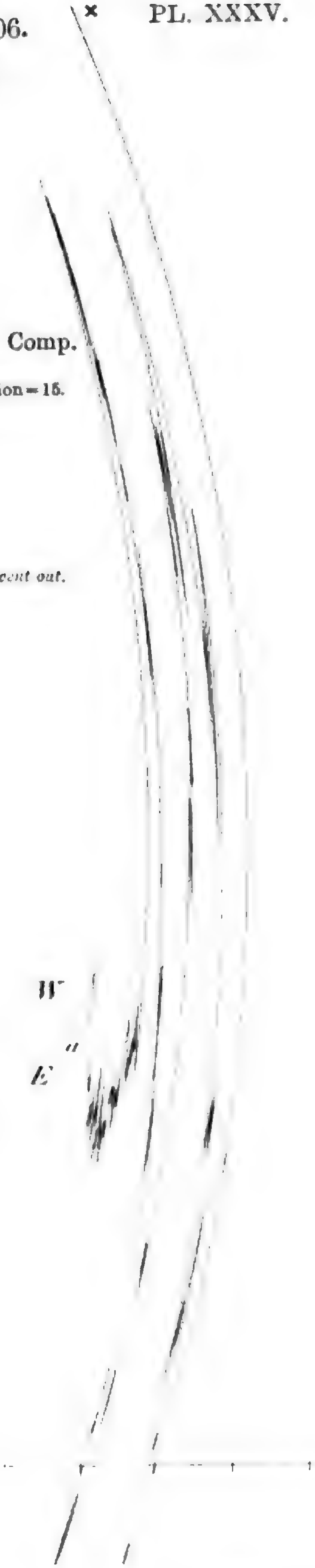


Fig. 10. EW Comp.

Multiplication = 15.

Earthquake of Jan. 21, 1906; 10.50 p.m. (Japan Time).

Fig. 11 and Fig. 12. Vertical component, observed in Tokyo.

Fig. 11.

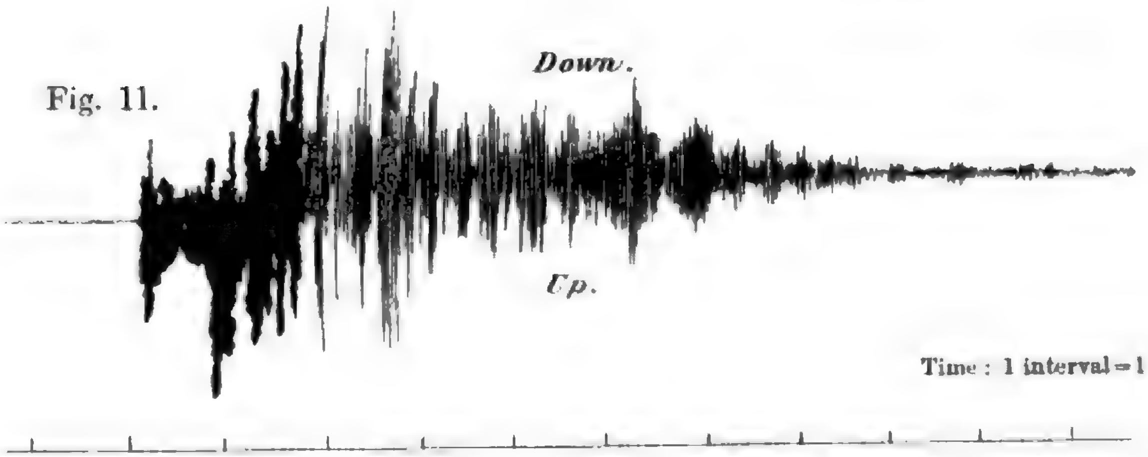
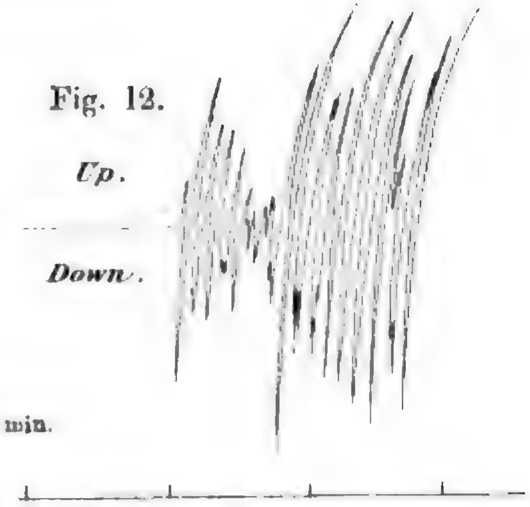


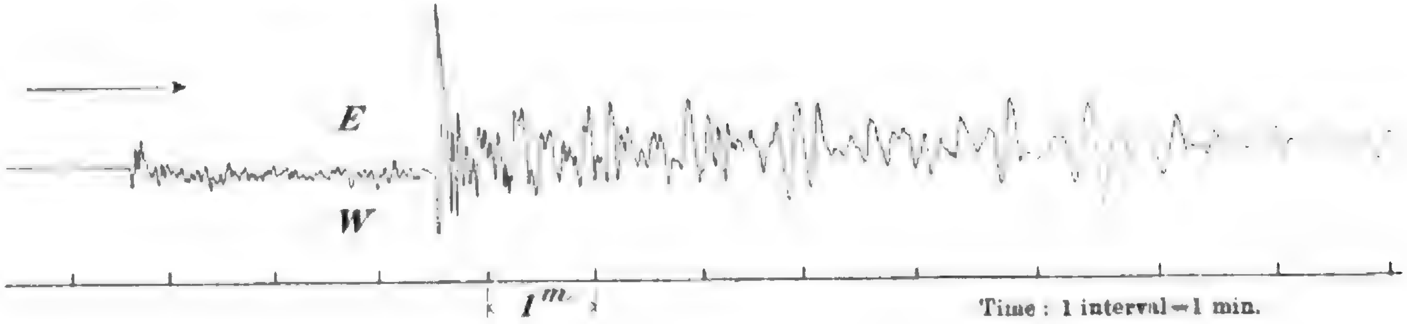
Fig. 12.



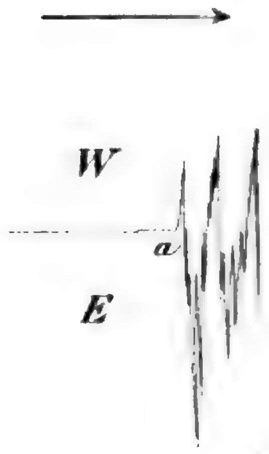
Time : 1 interval = 1 min.

Fig. 13. Observation at Taihoku, Formosa.

EW Component. Multiplication = 10.



Time : 1 interval = 1 min.


W
a
E

Vibrations of a Railway Bridge Pier.

By

F. Omori, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

A preliminary series of the measurement of the vibrations of railway bridge piers was carried on in 1901, the first report on this subject having been given in the *Publications of the Earthquake Investigation Committee*, No. 12. I have continued these measurements with my horizontal tremor recorder, in which the two horizontal component pointers had each a magnification of 10 to 50 times, the registration being made in ink on white paper driven by rollers. The diagrams obtained were, as shown in Pl. XXXIX, very good.

Tone-gawa Bridge, near Toride Station, Nippon Railway. This single-track (3′ 6″ gauge) bridge consists of eight 200′ Double Warren trusses and twenty-two 60′ plate girders. On Aug. 27, 1904, I have made a series of measurements of the vibrations of the pier between the 7th and 9th 200′ trusses,* (counted from the Tokyo end of the bridge). The pier experimented on was built of brick and had a total height of 94′.2, of which 29′.35 was above the river bed and had a thickness of 10′, while the remaining 64′.86 formed the well and had a thickness of 12′; the depth of water being about 10′. † The tremor recorder was set up on the top of the pier; Pl. XXXVIII being a picture of the instrument. Pl. XXXIX is one of the diagrams obtained, and magnifies 30 times both the longitudinal and transverse vibrations; these two latter being respectively the movements of the pier perpendicular and parallel to its face or plane. The motion was caused, in the case under consideration, by an up train consisting of a locomotive and 44 goods wagons at a slow speed. As will be seen from Pl. XXXIX, the greatest transverse vibrations occurred not at the moment of the transit of the locomotive, but when the end car of the train was just passing over the pier; there being a series of maximum movements, which corresponded to the successive piers, on account of the transmission of the transverse motion of the differrent piers through the means of the girders. Again, the longitudinal vibration was by no means small, as ought to be. In fact, as shown in my previous paper, a pier which rises from soft and muddy river bed does not vibrate with its base, that is to say, junction with the well as the centre or fixed point; the real position of the latter being a considerable distance below the ground surface. In our case, the centre of vibration is 40′ or 50′ deep; the pier (and the well) with the girders thus forming virtually a tall brick column, 60′ or 70′ in height, with heavy top load. Hence it is natural that the pier should vibrate parallel to its face as well as at right angles to the latter. The elements of motion were as follows:—

---

* This is one of the piers experimented on in 1901.

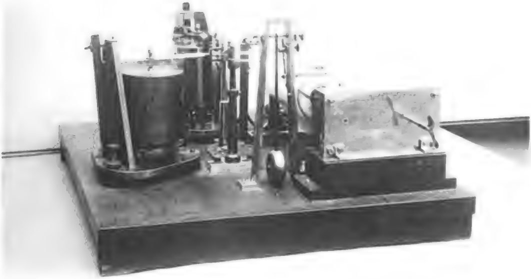
† The elevation and plan of the pier is given in the *Publications*, No. 12.

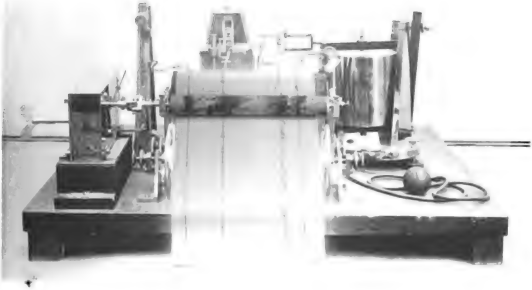
Transverse Vibration.

{Complete Period=0.39 sec., max. motion=0.63 mm;
{ ,, =0.18 ,, , ,, =0.08 ,,

Longitudinal Vibration.

Complete Period=0.22 sec., max. motion=0.33 mm, Horizontal Vibration Recorder.





PL. XXXIX.

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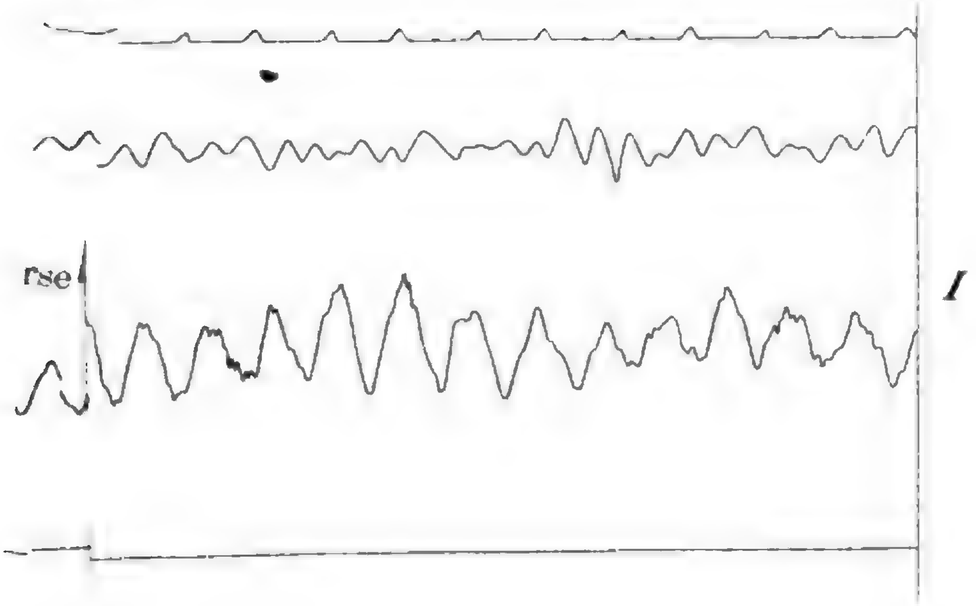
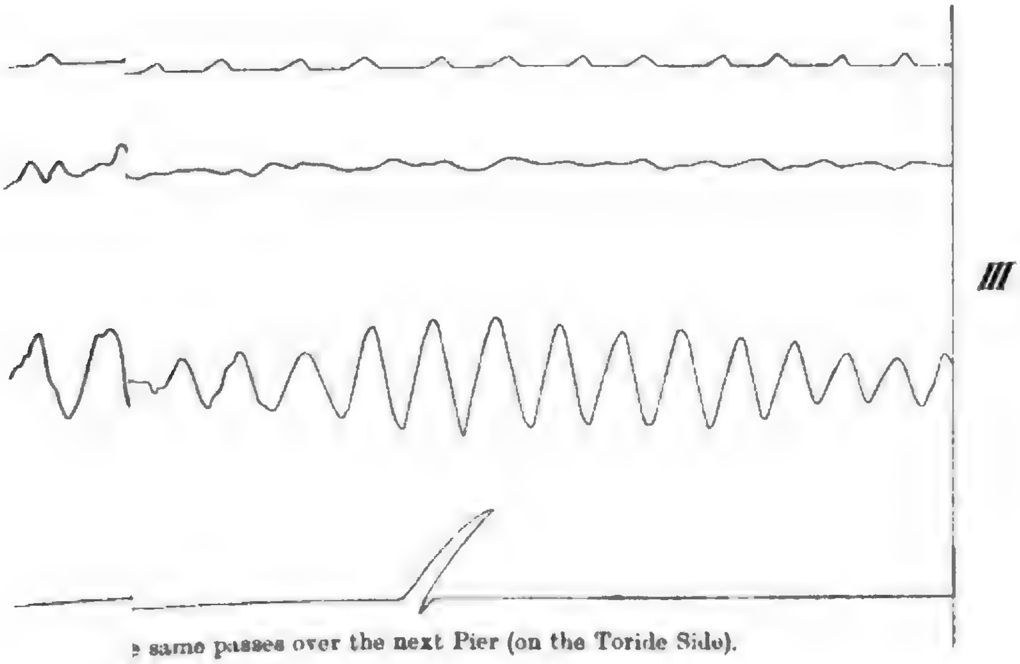
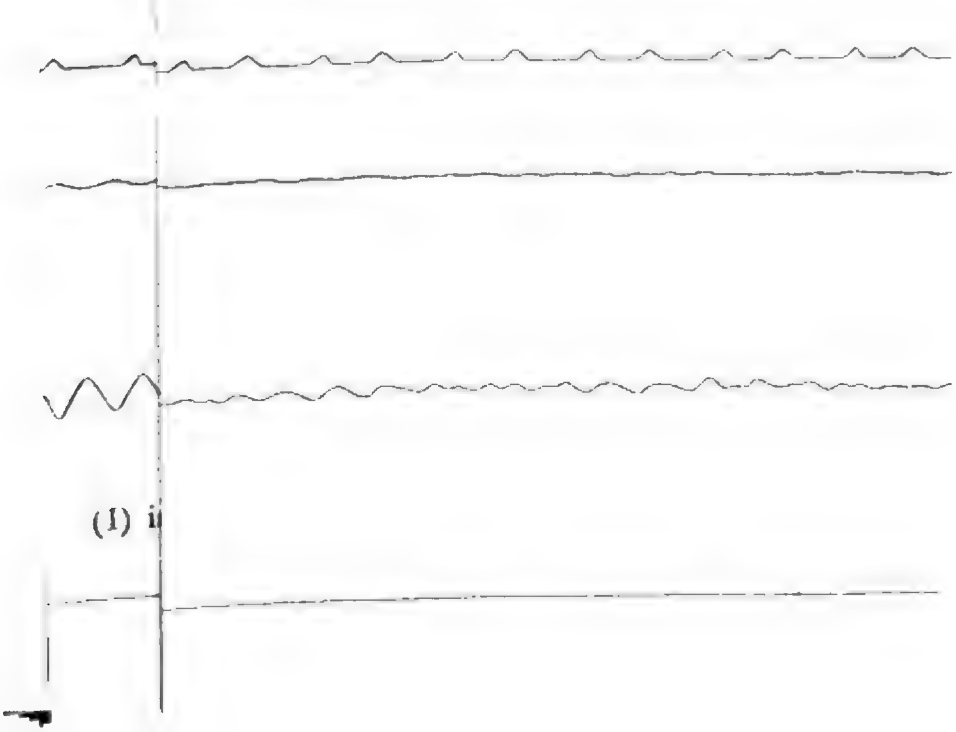




same passes over the next Pier (on the Toride Side).



there being also some traces of slow movements of period of 0.7 sec., due probably to the effect of the lateral vibration of the 200′ girders. Towards the end, the movements became small and regular, there being the following two sets of motion:—

$$\begin{cases} \text{Complete Period} = 0.37 \text{ sec.} \\ \quad\quad ,, \quad\quad\;\; = 0.24 \;\; ,, . \end{cases}$$

Thus in this case the amplitude of the longitudinal vibration was half of that of the transverse vibration. But as the periods of the principal movements in these two components were 0.39 and 0.22 sec. respectively, it comes out that the acceleration of the longitudinal vibration was nearly double that of the transverse. If we further take into consideration the fact that the breadth of the pier was not less than twice the thickness, the great importance of the longitudinal vibration in its relation to the strength of the pier will be readily recognised.

A full report on the measurement of the vibrations of the different brick and iron piers will be given in a future number of the *Publications*.

On a Method of Suppressing Air Tremors Occurring in Milne H. P. Seismograms.

By

A. Imamura, Sc. D.,

Extraordinary Member of the Imperial Earthquake Investigation Committee.

The principal disturbing cause in Milne H. P. Seismograms is probably the appearance of the so-called *air tremors*, especially in cold weather during night and early morning, which obscure the earthquake motion occurring at these times. This disturbance is known as an effect of convection current of the air within the instrument case, which cools in its upper part in consequence of quick radiation, while the air near the record-receiver and forming the middle layer in the case becomes comparatively warm under the influence of the lighted lamp.

Our instrument room is bounded with a metallic covering within a small building (1.5×1.8×2.0 m.) with wooden walls and a metallic roof.* This construction was evidently favorable for the occurrence of the disturbance in question, for the air tremors which occurred very much during the colder months could not be completely suppressed even under the contrivance due to Mr. Moos.† After carrying on the observation in this way for several winters, I have arrived finally at a means which seems to be fairly satisfactory.

---

* See the *Publications of the Imp. Earthq. Inv. Comm.*, No. 16, p. 1.

† See Prof. Milne: Fourth Report of the British Association Seismological Committee.

Figs. 1–2 show the front and lateral views of the new arrangement. The shaded part is the brick pier upon which the instrument case represented with dotted lines is mounted. Over this inner case, another wooden covering shown in the figures with full lines was newly added. The new case is divided into two parts; the upper one, which fits closely to the lower along the lines AB and BC, can be lifted up by means of two suspenders Dd and Ee. The lamp is also covered with a small metallic case from which a chimney projects out. A fresh supply of air is to be drawn through the pipe pp from outside, while the colder air within the outer covering can escape from the lower side of the latter. Further, the covering is provided at the front side with a door and a window as the gates for the record-receiver and the lamp respectively.

Fig. 1.

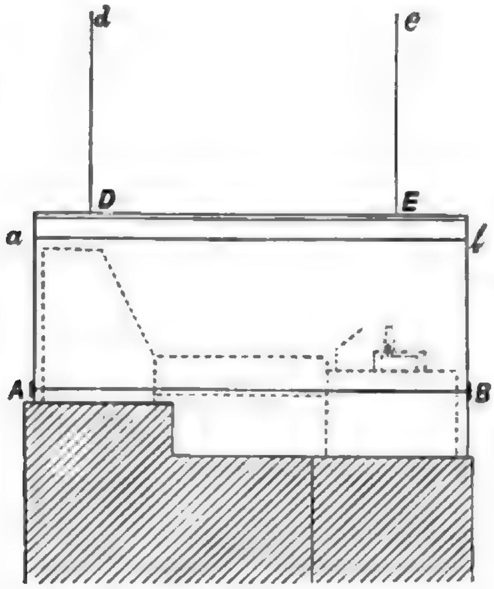
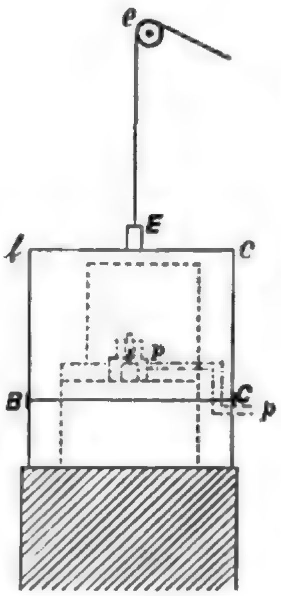


Fig. 2.



The object of the present arrangement is to warm the upper layer of air within the two coverings and consequently to prevent the raising of convection current within the inner covering. Since the instrument was covered with the outer case at the beginning of the last month it has not almost been affected by the air tremors, notwithstanding the season was hitherto an unfavorable one. During this experiment the free vibration period of the boom was kept at 15 sec., but perhaps it can advantageously be increased to 20 sec. or more without being much affected by any residual air tremors.

Tokyo.

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Note on the Kashgar (Turkestan) Earthquake of Aug. 22, 1902.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. *Position of the Earthquake Origin.* According to a map showing the isoseismal lines of the earthquake in question, given by Mr. A. Voznessensky in No. 4 of the "Bulletin Sismique de l'Observatoire Magnétique et Météorologique d'Irkoutsk," the earthquake origin seems to be situated at about *latitude* 39°42′ N, and *longitude* 76°E. This position has been assumed to be the source of disturbance in the calculation of the epicentral distances of different stations.

The times are, unless otherwise stated, always given in G.M.T.

2. *Approximate Time ($=t_0$) of Earthquake Occurrence at the Origin.*

(i) The epicentral distance of Taschkent, which was nearest the centre of disturbance is only 5°21′, the time of occurrence of the earthquake there being $3^h02^m12^s$. If we assume the mean transit velecity between the origin and Taschkent to be 6 km per sec.,* the time required by the vibrations of the 1st preliminary tremor in passing through that distance would be 91 sec., giving the following value for the time of occurrence at the origin:

$$t_0=3^h00^m41^s$$

---

* The "Publications," No. 13.

(ii) Taking the observation made in Tokyo, and using the formula

$$t_0 = t_1 - 1.165\ y_1^*,$$

we find:—

t_1 = Time of occurrence in Tokyo $= 3^h 09^m 33^s$

y_1 = Duration of 1st Prel. Tremor $= 6^m 44^s$

$t_0 = 3^h 00^m 43^s$

Taking the mean of the two above values of t_0, we obtain:— Time of earthquake occurrence at the origin,

$$t_0 = \mathbf{3^h 00^m 42^s}\ \text{(G.M.T.)}$$

3. *Time (t_1) of Eq. Occurrence at the different Stations.* The following table gives the latitude, longitude, and epicentral distance of, and the time of the earthquake occurrence at, each of the 36 different seismological stations, where the shaking was instrumentally observed.

Table I. Turkestan Earthquake: Epicentral Distance and Time of Occurrence.

Place.	Position.				Epicentral Distance $=x$.	Time of Eq'ke Occurrence (G.M.T.) $=t_1$.
	Latitude.		Longitude.			
Origin	**39° 42′**	N	**76°**	E	....	**3ʰ 00ᵐ 42ˢ**
(i) Taschkent	41° 19′ 31″	N	69° 17′ 42″	E	5° 21′	3ʰ 02ᵐ 12ˢ
Colaba (Bombay) ...	18 53 45	N	72 48 56	E	20 59	05 24
Irkutsk	52 16 --	N	104 18 33	E	23 07	05 24
Tiflis	41 43 08	N	44 47 51	E	23 36	05 14
(ii) *Mean*	....	...	... .		**22 34**	**3 05 21**
(iii) Kodaikanal	10 13 50	N	77 27 46	E	29 30	3 04 48
Nikolajev	46 58 18	N	31 58 27	E	32 24	07 00

---

* The "Bulletin," No. 1

Table I. *Cont.*

Place.	Position.				Epicentral Distance $=x$.	Time of Eqke Occurrence (G.M.T.) $=t_1$.
	Latitude.		Longitude.			
Pavlovsk……………	59° 41′ —″	N	30° 29′ 15″	E	34° 35′	3ʰ 07ᵐ 48
(iv) *Mean*……………	………………		………………		**33 30**	**3 07 24**
Budapest……………	47 22 29	N	19 03 55	E	41 02	3 09 20
Laibach ……………	46 03 —	N	14 31 —	E	44 22	06 50
Leipzig ……………	51 20 06	N	12 23 30	E	44 34	08 01
Triest ………………	45 38 45	N	13 45 45	E	44 59	08 17
Hamburg …………	53 33 55	N	10 01 19	E	45 35	08 55
Ischia ………………	40 40 —	N	13 59 —	E	46 22	10 05
Manila………………	14 34 41	N	120 58 33	E	46 34	09 04
Catania ……………	37 29 —	N	15 04 —	E	46 44	08 59
Ōsaka ………………	34 42 —	N	135 31 —	E	46 48	09 04
Rocca di papa………	41 46 —	N	12 42 —	E	46 54	08 30
Quarto-Castells ……	43 49 11	N	11 13 11	E	47 15	08 53
Strassburg …………	48 35 —	N	7 46 10	E	48 06	10 00
Pavia ………………	45 11	N	9 09	E	48 13	08 52
Tokyo………………	35 42 29	N	139 45 53	E	49 32	09 33
Uccle ………………	50 47 53	N	4 21 44	E	49 35	09 06
(v) *Mean* ……………	………………		………………		**46 26**	**3 08 54**
Edinburgh …………	55 57 23	N	3 10 46	W	52 24	3 09 30
Shide ………………	50 42	N	1 19	W	53 02	10 12
Paisley . …………	55 51	N	4 25	W	53 05	10 10
Liverpool …………	53 24 04	N	3 04 18	W	53 09	…………
Batavia ……………	6 08	S	106 50	E	53 56	09 54
(vi) *Mean* …………	………………		………………		**53 07**	**3 09 54**
(vii) San Fernando…	36 27 40	N	6 12 19	W	62 23	3 09 06

Table I. *Cont.*

Place.	Position.				Epicentral Distance $=x$.	Time of Eqke Occurrence (G.M.T.)$=t_1$.
	Latitude.		Longitude.			
Perth (W.A.)	31° 52′ —″	S	115° 50′ —″	E	80° 32′	3^h 13^m 36^s
Cape Town............	33 56 03	S	18 28 41	E	90 47	14 48
Victoria, B.C.	48 27 —	N	123 22 —	W	90 12	16 00
Toronto*...............	43 39 36	N	79 23 24	W	93 43	25 48
Baltimore*	39 17 48	N	76 37 12	W	97 08	24 30
(viii) *Mean* .... (*Excluded)	....		....		**87 10**	**3 14 48**
Christchurch	43 31 50	S	172 37 18	E	120 17	3 20 36
Wellington*	41 17 —	S	174 47 —	E	120 39	29 00
(ix) *Mean*................ (*Excepted)	....		... .		**120 17**	**3 20 36**
(x) Cordova............	31 26 —	S	64 12 —	W	146 52	3 19 30

Propagation Velocity v_1, calculated by "Difference Method." The mean group values of the epicentral distance (x) and the corresponding time (t_1) of earthquake occurrence are, according to the above table, as follows:—

(i) $x=$ 5° 21′ ; $t_1=3^h02^m12^s$ (1 station)
(ii) 22 34 3 05 21 (3 stations)
(iii) 29 30 3 04 48 (?) (1 ,,)
(iv) 33 30 3 07 24 (2 ,,)
(v) **46 26** **3 08 54** (15 ,,)
(vi) 53 07 3 09 54 (5 ,,)
(vii) 62 23 3 09 06 (?) (1 ,,)
(viii) 87 10 3 14 48 (5 ,,)
(ix) 120 17 3 20 36 (1 ,,)
(x) 146 52 3 19 30 (1 ,,)

The values of the velocity v_1 calculated by combining the group (v) with the others are given in the following table:—

Velocity v_1 Calculated by "Difference Method."

Combination of Groups.	δx	δt_1	v_1
(v)—(iv)	12° 55′	$1^m 30^s$	15.9 km/sec.
,, —(ii)	23 52	3 33	12.4
,, —(i)	41 05	6 42	11.4
(vi)—(v)	6 41	1 00	12.4
(viii)— ,,	40 44	5 54	12.8
{(ix) (x)}— ,,	87 09	11 09	14.4

The average of the velocity, deduced from the 6 different values contained in the above table is

$$v_1 = \mathbf{13.2} \text{ km/sec.}$$

This is to be regarded only as a rough approximation.

4. ***Duration of the 1st Preliminary Tremor.*** Table II gives for a number of stations the epicentral distance and the duration (y_1) of the 1st preliminary tremor.

Table II. Turkestan Earthquake: Duration of the 1st Preliminary Tremor.

Place.	Epicentral Distance $= x$.	Duration of 1st Prel. Tremor $= y_1$.
Colaba (Bombay)	20° 59′	$3^m 54^s$
Kodaikanal (Madras)	29 30	5 06
Pavlovsk	34 35	6 06
Mean	**28 21**	**5 02**
Leipzig	44 34	7 35
Ōsaka	46 48	7 12

Table II. *Cont.*

Place.	Epicentral Distance $=x$.	Duration of 1st Prel. Tremor $=y_1$.
Quarto-Castello	47° 15′	7m 39s
Tokyo	49 32	6 44
Mean	**47 02**	**7 18**
Edinburgh	52 24	8 00
Batavia	53 56	8 00
Mean	**53 10**	**8 00**
San Fernando	62 23	10 12
Cape Town	90 47	9 30
Baltimore	97 08	8 48
Christchurch	120 17	20 36
Cordova	146 52	21 42
Mean	**133 35**	**21 09**

Taking provisionally only the 4 mean group values of the x and the corresponding y_1 contained in Table II, and calculating by the method of Least Squares the constants of a linear equation assumed between these two quantities, we obtain the following result:—

$$x^{km}=11.8y_1^{sec}-60^{km}$$

(for x between 28° and 134°)

The above equation, which is to be regarded as being only roughly approximate, relates to the observation of the Turkestan earthquake at different places. (Compare with a similar equation for the San Francisco earthquake of April 18, 1906, given in the *Bulletin*, No. 1.)

Tilting of the Ground during a Storm.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. In the "Publications of the Earthquake Investigation Committee", No. 21, I have described an EW horizontal pendulum or "tiltometer" diagram obtained in Tokyo during a storm, on Oct. 10th and 11th, 1904, which shows the tilting of the ground to an amount of $3\frac{1}{2}''$. Fig. 1, Pl. XL, illustrates a similar case of the tilting of the ground observed on Jan. 10 and 11, 1906, in Tokyo, with the EW component horizontal pendulum, whose recording cylinder makes one revolution in 24 hours. The instrument, which is set up in the brick "Earthquake-proof House" in the University Compound (Hongō), is of the following specifications:—

Length of the strut, or the horizontal distance between the pendulum axis and the centre of the heavy bob $=L=75^{\text{cm}}$.

Period of the pendulum when suspended vertically $=T_0=1.74$ sec.

Period of the horiz. pendulum as actually set up $=T=33$ sec.

Multiplication ratio of the pointer $=n=20$.

1mm displacement of the writing index $=$

$$r=L\times n\times \sin 1''\times \frac{T^2}{T_0^2}=0.''0385$$

2. ***The Weather at Tokyo on Jan. 10 and 11, 1906.***[*] The following table gives the hourly values at Tokyo on Jan. 10th and pulsatory oscillations became very active, and reached a maximum range of 0.2 mm. Then there began the tilting of the ground towards W, and the maximum displacement of the pointer (marked *c* in the figure) in that direction occurring at $8^h\ 31^m$ a.m. on the 11th. The total or double amplitude of the tilting oscillation amounted to 74.6 mm or 2.″87.

---

[*] The times are given in 1st Normal Japan Time, or that of longitude 135° E.

After $8^h\ 31^m$ the tilting began to turn towards E again, the pulsatory oscillations becoming at the same time still more active.

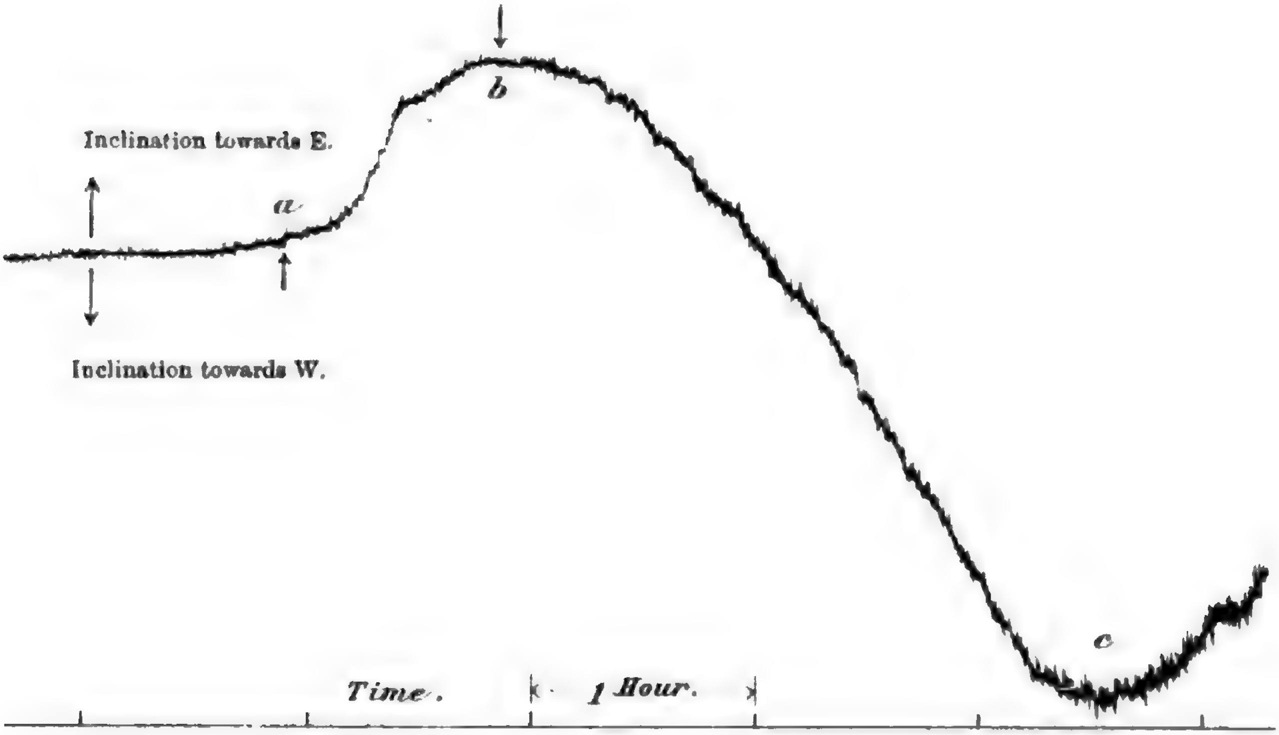
The pointer reached its normal position at about $3^h\ 15^m$ p.m., on the 11th; the pulsatory oscillations continuing active (maximum range=0.25 mm) till that time.

Fig. 2 and Fig. 3 give the records furnished by a horizontal pendulum tromometer of multiplication=120, also set up in the "Earthquake-proof House", for a few minutes interval, respectively at about 2 and 4 a.m., on the 11th. The elements of motion were as follows:—

2 a.m. (11th).......max. range=0.17 mm, period=6.2 sec.
4 ,, ,, =0.15 ,, , ,, 6.4 ,, .

4. From §§ 2 and 3, it will be seen that the extreme elongation towards E (*b* in Fig. 1) coincided with the epoch of the greatest rainfall, and that the remarkable westward tilting from *b* to *c* nearly coincided with the time interval during which the atmospheric pressure was lowest, namely, between 6 and 9 a.m. (on the 11th). Now the existence of a barometric depression on Musashi, Shimosa and Hitachi plain, or the district lying to the east and north-east of Tokyo, would cause this part of the earth's surface to rise up, the consequence being that there ought to be a westward inclination (*bc*) at Tokyo and the neighbourhood. A similar explanation is applicable to the eastward inclination (*ab*).

Fig. 1. EW Tiltometer Record. Jan. 11, 1906; Hongō, Tokyo.



Pulsatory Oscillations, Observed at Hongō, Tokyo. Jan. 11, 1906. EW Component.
Multiplication = 120.

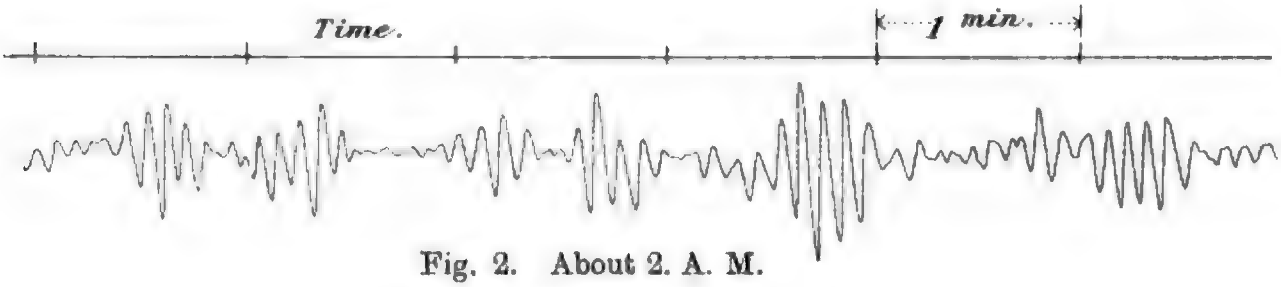


Fig. 2. About 2. A. M.

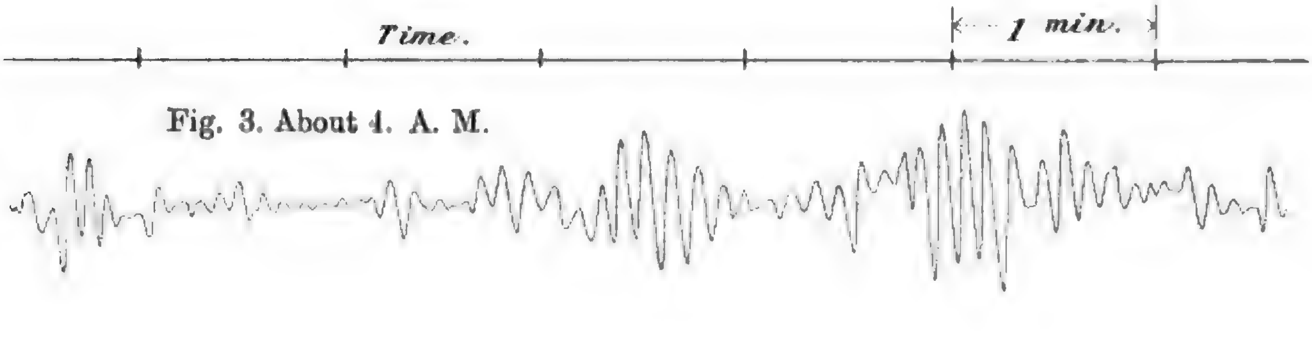


Fig. 3. About 4. A. M.

The demonstration suggested above is rather opposite to that used for the case of the tilting observed in Tokyo on Oct. 10 and 11, 1904. The discrepancy probably lies in the fact that on the latter occasion, the depression moved entirely over the Pacific at a distance of several hundred km. from the coast, while in the present case the track of the cyclone was entirely over the land, from its first entrance in Kyushu to its passage into the ocean at the coast of Hitachi.

Tiltometer observations of the effects of the barometric pressure simultaneously in two rectangular horizontal directions seem to be very interesting in connection with the question of the rigidity of the earth's crust.

The Deflection and Vibration of Railway Bridges. 2nd Paper.

By

F. Omori, Sc. D.,
Member of the Imperial Earthquake Investigation Committee.

1. *Introduction.* In No. 9 of the *Publications of the Earthquake Investigation Committee in Foreign Languages,* I have given an account of the measurements of the deflection and vibration of eleven railway bridges, with description of the instruments employed. Since then these experiments have been greatly extended, and in the course of 1901 and 1902, the movements of the 24 different girders and trusses on the Government, the Nippon, and the Kwansei Railways have been examined. All the trusses were *through* in construction except the two similar 105′ Pratt trusses of the 5th Aizawa-*gawa* and the Kami Usui-*gawa* bridges which were *deck* in construction. All of these bridges, most of which are constructed according to the Imp. Jap. Gov. Railway Standard, are for single track. In a few cases, the vibration of the bridge piers have also been recorded. The present note gives a tabular statement of the results of these measurements; the full report will be given in a future number of the *Publications.*

2. *Instruments.* The measurement of the deflection and vibration of the bridge trusses and girders was done with the same instruments and in exactly the same way as in the preceding series of experiments For taking the direct measurement of the total amount of the deflection, however, a new self recording arrangement was designed, whose mechanical details an given in Pl. XLI. This instrument consists essentially of a strong wooden board (*a*), 5 inches broad and some 3 feet long, which is fixed by means of proper bolts or hooks (*b*) to the girder or the bottom chord of the truss. From the middle of the plate, rises a wooden post (*c*) about 1′ tall, whose top serves as the fulcrum for the lever (*de*). One end of the latter is stretched by three similar powerful spiral springs (*k*) fixed vertically to the plate (*a*); while from the other end, (*e*), a square piece of wood (*f*) is suspended, which is to be tightly stretched by means of a weight (*g*), (not shown in the figure) suspended with a steel wire or tape. To the inner side of the wood piece (*d*) is fixed by a screw a small thin rectangular piece of wood, (*h*), about 1″×5″ in size, against which presses the point of a pencil (*i*) contained in a guiding tube (*j*) fixed to the base plate. The tube (*j*) contains at its end a small spiral spring which presses the pencil (*i*) forward. Thus, when a train passes over the girder or truss, the latter is deflected and bent down; while the small plate (*h*) remains always in its position, on account of the stretching due to the weight (*g*) and the springs (*k*).

The pencil (*i*) therefore traces in the natural size the amount of the total deflection (i. e. statical deflection and maximum vertical vibration combined) on the plate (*h*). The latter is after each experiment to be substitued by a new one. Except for the case of mountain torrent, this method gave generally satisfactory results, no matter how deep the water was; the weight (*g*) consisting of a cylindrical weight of lead furnished with three small feet, which together weigh about 15 kg. The following are some of the cases, in which the deflection was measured both directly by the above mentioned contrivance, and by the vertical motion seismograph (deflectometer) set up on the bridge itself:—

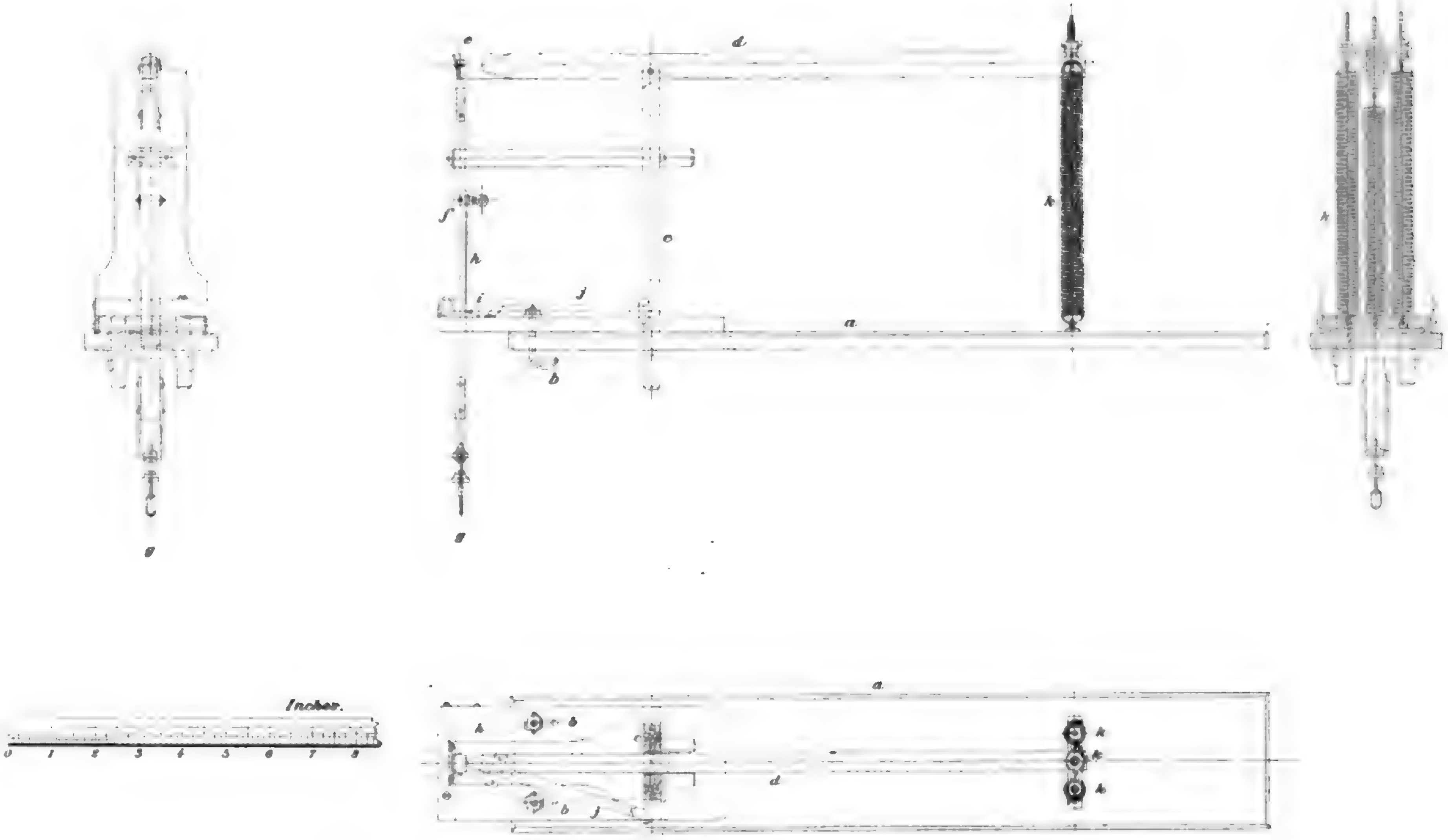
Bridge.	Deflection measured directly.	Deflection measured by vert. mot. seismograph.	Remarks.
Ōi-*gawa.* (Tokaido Ry.) 200′ Double Warren Gird.	24.0 mm	26.2 mm	Passenger train, with 2 engines Nos. 608 and 2 at head.
Do.	19.0	21.0	Mixed train, with 2 engines Nos. 610 and 113 at head.
Ibi-*gawa* (Kwansei Ry.) "	18.0	17.4	Passenger train, Engine No. 44.
Do.	19.0	17.5	Passenger train, Engine No. 41.
Mean.	**20.0**	**20.5**	

3. Deflection and Vibration of the Bridge Girders and Trusses. Table II, which embodies the results of the second series of the deflection and vibration measurements, gives for each of the bridge girders and trusses the different elements of the movement; the experiment having been, except in a few cases, repeated 2 to 21 times. Table III gives a general summary of the results of measurements contained in Table II, namely, the absolutely greatest and mean maximum values of the deflection, double amplitude, and period, for each case. Table I gives a list of the locomotives which passed over the different bridges during the experiments. The terms *deflection*, and *vertical*, *transverse* and *longitudinal vibrations*, which are used in the same senses as heretofore and refer to the middle of the bottom side of a girder or truss, are defined as follows:—

The *deflection* is the total amount of bending, which is equivalent to the sum of the statical bending and the maximum vibration amplitude.

The *vertical vibration* is the up and down quick movement,

A Contrivance for measuring the Deflection of a Bridge.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whose period depends on each girder or truss; while the *transverse* and the *longitudinal vibrations* are the movements, which take place in the horizontal plane, and whose directions are respectively perpendicular and parallel to the length of the bridge. For each class of vibrations, the range of motion, or double amplitude, and the period (that is to say, the complete period) are denoted respectively by the symbols 2a and T.

The values of the deflections given in Tables II and III have been obtained as follows:—(1), measured by the deflectometer alone in the cases of a 70′ plate girder of the Tone-*gawa* (Maebashi), the three 100′ Warren girders of the Kuji-*gawa*, the 2nd Sakawa-*gawa* and the 3rd Sakawa-*gawa* bridges, the 120′ Pratt truss of the Ibi-*gawa* bridge, the two similar 105′ Pratt deck trusses (up line) of the 5th Aizawa-*gawa* and the Kami-Usui-*gawa* bridges, and the 200′ Pratt truss of the Kizu-*gawa* bridge; (2), measured directly by the contrivance before described, in the cases of the 20′ plate girder of the Tone-*gawa* bridge (Toride), the 70′ plate girder of the Kizu-*gawa* bridge, the 100′ Warren girder (one nearest the Kasagi end) of the Kizu-*gawa* bridge, the 105′ Pratt truss (down line) of the 5th Aizawa-*gawa* bridge, a 200′ Double Warren girder (Truss No. 14) of the Ōi-*gawa* bridge, the 200′ bow-string truss of the 3rd Aizawa-*gawa* bridge, and a 200′ Double Warren girder (No. 1) of the Tone-*gawa* bridge (Toride); and, (3), measured both by the deflectometer and directly by the same contrivance as in (3), in the remaining 4 cases.

The period of the longitudinal vibration which was generally too quick to be distinctly measured by our instrument, is not given in the tables.

The *asterisks*, affixed in Table III to the names of some of the bridges signify that the values of the deflection and the vibrations given there are those caused by the passage of the heaviest engine or train which pass over those bridges in the present state of the traffic on the different Japanese railways. In Table III, the absolutely greatest among the different values of a given element of motion in each column are printed in fat letters.

A photographic picture of the contrivance for directly measuring the deflection, described in § 2, is given in Pl. XLII.

TABLE I.—LIST OF THE LOCOMOTIVES.‡

No.	Class.	Total Weight			Weight of Tender.			No.	Class.	Total Weight			Weight of Tender.		
NIPPON RAILWAY.*															
		T	C	Q	T	C	Q			T	C	lbs	T	C	lbs
38	Tank Engine	33.	8.	2		—		513	Tender Engine	70.	16.	118	26.	13.	26
62	,, ,,	44.	15.	0		—		515	,, ,,	,,	,,	,,	,,	,,	,,
123	,, ,,	38.	19.	3		—		524	,, ,,	,,	,,	,,	,,	,,	,,
209	Tender ,,	55.	16.	0	24.	10.	0	527	,, ,,	,,	,,	,,	,,	,,	,,
211	,, ,,	,,	,,	,,	,,	,,	,,	535	,, ,,	80.	0.	122	26.	13.	26
508	,, ,,	70.	16.	lbs 118	26.	13.	lbs 26	553	Tank ,,	39.	9.	12		—	
510	,, ,,	,,	,,	,,	,,	,,	,,	555	,, ,,	,,	,,	,,		—	
511	,, ,,	,,	,,	,,	,,	,,	,,								
KWANSAI RAILWAY.															
		T	C	Q	T	C	Q			T	C	Q	T	C	Q
24	Tender Engine	62.	17.	3	25.	17.	3	36	Tender Engine	64.	0.	0	23.	10.	0
27	Tank ,,	36.	2.	0		—		38	,, ,,	,,	,,	,,	,,	,,	,,
29	,, ,,	,,	,,	,,		—		39	,, ,,	,,	,,	,,	,,	,,	,,
30	Tender ,,	64.	0.	0	23.	10.	0	40	,, ,,	54.	4.	0	18.	10.	0
31	,, ,,	,,	,,	,,	,,	,,	,,	41	,, ,,	,,	,,	,,	,,	,,	,,
33	,, ,,	,,	,,	,,	,,	,,	,,	42	,, ,,	,,	,,	,,	,,	,,	,,
34	,, ,,	,,	,,	,,	,,	,,	,,	44	,, ,,	,,	,,	,,	,,	,,	,,
35	,, ,,	,,	,,	,,	,,	,,	,,								
GOVERNMENT RAILWAYS.															
		T	C	Q	T	C	Q			T	C	Q	T	C	Q
2	Tender Engine	42.	14.	0	17.	6.	0	272	Tender Engine	59.	8.	0	22.	2.	0
74	Tank ,,	45.	9.	2		—		278	,, ,,	,,	,,	,,	,,	,,	,,
113	,, ,,	33.	8.	2		—		289	,, ,,	,,	,,	,,	,,	,,	,,
187	Tender ,,	60.	19.	0	22.	0.	0	299	Tank ,,	48.	9.	0		—	
188	,, ,,	,,	,,	,,	,,	,,	,,	324	,, ,,	,,	,,	,,		—	
189	,, ,,	,,	,,	,,	,,	,,	,,	325	,, ,,	,,	,,	,,		—	
190	,, ,,	,,	,,	,,	,,	,,	,,	505	Abt ,,	53.	12.	0		—	
191	,, ,,	,,	,,	,,	,,	,,	,,	605	Tender ,,	46.	17.	0	19.	10.	0
193	,, ,,	,,	,,	,,	,,	,,	,,	606	,, ,,	,,	,,	,,	,,	,,	,,
194	,, ,,	,,	,,	,,	,,	,,	,,	608	,, ,,	,,	,,	,,	,,	,,	,,
197	,, ,,	,,	,,	,,	,,	,,	,,	610	,, ,,	,,	,,	,,	,,	,,	,,
199	,, ,,	,,	,,	,,	,,	,,	,,	612	,, ,,	,,	,,	,,	,,	,,	,,
200	,, ,,	,,	,,	,,	,,	,,	,,	634	,, ,,	,,	,,	,,	,,	,,	,,
203	,, ,,	,,	,,	,,	,,	,,	,,	640	,, ,,	,,	,,	,,	,,	,,	,,

‡ *Total weight* is the weight of the engine and tender.

* The Nippon Railway has recently been nationalized.

TABLE II. DEFLECTION AND VIBRATION

River.	Bridge Girder or Truss.	Deflection.			Vertical Vibration.	
		Instrumentally measured. (mm)	Directly measured (mm)	Mean. (mm)	2a (mm)	T (s)
Tone (Toride) (Nippon Ry.)	20′ Plate Girder	—	2.1	—	—	—
		—	2.9	—	—	—
	60′ „ „	10.8	—	—	1.0	0.21
		8.5	—	—	1.2	0.24
		11.1	—	—	1.5	0.22
		9.1	10.3=($\frac{13}{32}$″)	9.7	1.0	0.22
		8.0	10.3=(„)	9.2	1.2	0.26
		—	9.5=($\frac{3}{8}$″)	—	—	—
Kuji (Ōmika) (Nippon Ry.)	60′ „ „	—	12.5	—	—	—
		—	12.4	—	—	—
		—	12.4	—	—	—
Tone (Mayebashi) (Nippon Ry.)	70′ „ „	8.8	—	—	2.6	0.90
		7.5	—	—	1.7	0.22
		—	—	—	1.5	0.19
		8.8	—	—	2.0	0.21
		9.9	—	—	1.8	0.21
Kizu (Kasagi) (Kwansai Ry.)	70′ „ „	—	16.3	—	—	—
		—	14.5	—	—	—
		—	15.5	—	—	—
Kizu (Ōmika) (Nippon Ry.)	100′ Warren Girder	14.3		—	3.5	0.35
		16.4	—	—	5.6	0.34
		—	—	—	0.9	0.34
		17.8	—	—	5.4	0.34
(No. 2) Sakawa (Yamakita) (Gov. Ry.)	100′ „	14.7	—	—	3.2	0.35
		11.6	—	—	5.6	0.27
		13.3	—	—	3.2	0.32
(No. 3) Sakawa (Yamakita) (Gov. Ry.)	100′ „	15.4	—	—	5.1	0.29

OF RAILWAY BRIDGES IN JAPAN.

Transverse Vibration.		Longitudinal Vibration.	Time taken by Locomotive in passing over the Girder or Truss. (s)	No. of Locomotive.	Train.
2a (mm)	T (s)	2a (mm)			
—	—	—		200	Up, Passenger Train.
—	—	—	—	515	Down, ,, ,,
—	—	—	3.8	553	Up, Goods ,,
—	—	—	3.0	123	Down, ,, ,,
—	—	—	4.0	527	Up, Mixed ,,
—	—	—	3 2	62	Down, Goods ,,
—	—	—	4.2	555	,, ,, ,,
—	—	—	—	513	,, Mixed ,,
—	—	—	—	535	Up, Goods ,,
—	—	—	—	508	,, Passenger ,,
—	—	—	—	524	Down, ,, ,,
—	—	—	2.2	38	,, Mixed ,,
3.5	0.43	0.2	2.6	,,	Up, ,, ,,
2.0	0.32	1.0	—	,,	Down, Passenger ,,
3.2	0.40	Faint.	2.6	,,	Up, Mixed ,,
5.0	0.37	0.4	2.6	,,	Down, ,, ,,
—	—	—	—	31	Up, Mixed ,,
—	—	—	—	24	Down, Goods ,,
—	—	—	—	36	,, Express.
8.6	0.63	0.7	2.9	511	Down, Passenger ,,
10.0	0.99	0.9	3.2	508	Up, ,, ,,
6.3	1.06	0.4	6.9	535	,, Goods ,,
10.0	0.61	0.7	3.4	524	Down, Passenger ,,
6.5	0.76	1.3	4.4	{194 and 191, in series.	Up, Goods ,,
5.9	Vibration very quick.	2.7	2.3	199	,, Passenger ,,
10.2	1.09	—	3.8	{193 and 197, in series.	,, Goods ,,
—	—	—	4.0	{190 and 272, in series.	,, Passenger ,,

TABLE II.

River.	Bridge Girder or Truss.	Deflection.			Vertical Vibration	
		Instrumentally measured. (mm)	Directly measured. (mm)	Mean. (mm)	2a (mm)	T (s)
Kizu (Kasagi) (Kwansei Ry.)	100′ Warren Girder. (on Nagoya side).	12.0	—	—	3.7	0.30
		10.2	—	—	2.7	0.28
		9.3	—	—	2.3	0.27
		9.8	—	—	2.8	0.28
		11.3	—	—	2.1	0.25
		13.3	—	—	4.7	0.25
		—	11.5	—	—	—
		—	10.2	—	—	—
		—	10.4	—		—
		—	10.6	—		—
		—	9.2	—	—	—
		—	9.5	—	—	—
		—	14.0	—	—	—
,, (Do.)	100′ Warren Girder. (on Kasagi side).	—	10.2	—	—	—
		—	9.8	—		—
Ibi (Nagashima) (Do.)	120′ Pratt Truss.	7.2	—	—	1.6	0.25
		8.0	—	—	1.2	0.28
		5.3	—	—	1.0	0.21
No. 5. Aizawa (Oyama) (Gov. Ry.)	105′ Pratt Truss Deck.	25.4	—		5.8	0.33
		22.4	—	—	4.4	0.31
,, (Do.)	105′ (,,)	—	17.5	—	—	—
		—	15.0	—	—	—
Kami-Usui (Matsuida) (Do.)	105 (,,)	14.7	—		4.9	—
		17.2	—	—	6.8	0.28
		18.2	—	—	6.3	0.32
		17.7	—	—	4.3	0.28
		15.4	—	—	4.4	0.33

CONT.

Transverse Vibration.		Longitudinal Vibration.	Time taken by Locomotive in passing over the Girder or Truss. (s)	No. of Locomotive.	Train.
2a (mm)	T (s)	2a (mm)			
—	—	—	2.3	29	Up, Passenger Train, 11 Carriages
—	—	—	2.8	33	„ „ „ , 16 „
—	—	—	3.9	38	Down, Goods „ , 6 Wagons
—	—	—	3.4	33	Up, Passenger „ , 11 Carriages
—	—	—	3.4	38	„ , Goods „ , 11 Wagons
—	—	—	2.5	35	Down, Passenger „ , 10 Carriages
—	—	—	—	39	Up, „ „ , 11 „
—	—	—	—	30	Down, „ „ , 10 „
—	—	—	—	35	„ , Goods „ , 11 Wagons
—	—	—	—	33	„ , Passenger „ , 12 Carriages
—	—	—	—	30	Up, „ „ , 11 „
—	—	—	—	35	„ , Goods „ , 11 Wagons
—	—	—	—	31	Down, Passenger „ , 10 Carriages
—	—	—	—	34	Up, Goods „ , 4 Wagons
—	—	—	—	39	„ , Passenger „ , 10 Carriages
—	—	—	4.4	40	Down, Passenger „ , 10 Carriages
—	—	—	4.6	41	Up, Mixed „ , Pass., 6 Cars. Goods, 6 Wags.
—	—	—	4.3	27	Down, „ „ , Pass., 6 Cars. Goods, 6 Wags.
—	—	—	4.6	193 and 197, in series.	Up, Goods, „ , 26 Wagons
—	—	—	4.0	189 and 289, in series.	„ , Passenger „ , 20 Carriages
—	—	—	—	200	Down, Passenger „ , 9 Carriages
—	—	—	—	193	„ , Goods „ , 31 Wagons
—	—	—	—	74	„ „ „ , 10 Wagons
7.8	1.01	0.7	3.2	290	Up, „ „ , 12 „
6.2	0.99	1.1	3.3	325	Down, Mixed „ , Pass., 7 Cars. Goods, 3 Wags.
7.7	1.32	0.9	3.3	74	Up, „ „ , Pass., 6 Cars. Goods, 4 Wags.
5.4	0.99	0.7	3.6	299	Down, Goods „ , 13 Wagons

TABLE II.

River.	Bridge Girder or Truss.	Deflection.			Vertical Vibration.	
		Instrumentally measured. (mm)	Directly measured. (mm)	Mean. (mm)	2a (mm)	T (s)
Kami-Usui (Matsuida) (Gov. Ry.)	105′ (Pratt Truss Deck)	17.4	—	—	5.8	0.25
		16.7	—	—	5.7	0.28
		—	—	—	5.5	0.23
		14.8	—	—	6.1	0.32
		15.4	—	—	4.5	0.25
		17.0	—	—	3.8	0.37
		18.2	—	—	5.6	0.28
		—	—	—	6.3	0.28
		—	—	—	5.0	0.30
		—	—	—	6.8	0.31
		—	—	—	4.8	0.32
		—	—	—	5.9	0.26
		—	—	—	5.3	0.33
		20.2	—	—	9.2	0.30
		18.2	—	—	8.8	0.23
		—	—	—	4.9	0.33
		—	—	—	5.2	0.32
Ibi (Nagashima) (Kwansai Ry.)	200′ (Double Warren Girder)	17.4	18.0	17.7	3.9	0.36
		17.5	19.0	18.3	8.2	0.32
		—	18.2	—	4.4	0.46
		—	18.5	—	2.7	0.59
		—	16.5	—	5.6	0.44
		—	13.6	—	1.9	0.53
Oi (Kanaya) (Gov. Ry.)	200′ „ (No. 10 Girder)	—	—	—	—	—
		—	—	—	—	—
		26.2	24.0	25.1	7.2	0.39
		—	13.0	—	2.5	0.35
		—	15.8	—	3.8	0.40
		21.0	19.0	20.0	3.4	0.38
		—	—	—	0.4	0.37

CONT.

Transverse Vibration.		Longitudinal Vibration.	Time taken by Locomotive in passing over the Girder or Truss.	No. of Locomotive.	Train.
2a (mm)	T (s)	2a (mm)	(s)		
11.5	0.92	1.5	2.6	325	Up, Goods Train, 10 Wagons.
2.7	—	1.0	[illegible]	74	Down, Mixed „ {Goods, 1 Wags. Pass, 6 Cars.
8.1	1.15	1.0	2.6	299	Up, „ „ {Goods, 6 Wags. Pass, 6 Cars.
6.6	0.67	1.4	3.4	325	Down, Goods „ , 11 Wagons.
—	—	—	3.0	—	Up, „ „ „
3.8	0.99	1.0	3.3	325	Down. „ „ , 11 Wagons.
—	—	--	2.6	325	Up, Mixed „ , {Goods, 2 Wags. Pass., 8 Cars.
7.2	0.99	0.7	--	324	Down, Goods „ , 12 Wagons.
2.9	0.28	0.7	—	74	„ , Mixed „ , {Pass., 6 Cars. Goods, 4 Wags.
8.9	1.25	0.8	—	324	Down, Goods, „ , 12 Wagons.
11.5	1.21	--	4.8	605	Up, „ „
15.0	1.09	—	4.0	„	Down, „ „
12.0	1.24	—	4.8	„	Up, „ „
11.0	1.27	0.6	4.2	„	Down „ „
10.8	1.21	0.8	4.0	„	Down „ „
12.5	1.48	0.5	6.0	„	Up „ „
4.7	0.50	0.5	—	42	Up, Mixed Train, {Pass., 6 Cars. Goods, 18 Wags.
—	—	--	5.3	41	Up, Passenger „ , 10 Carriages.
—	—	—	5.0	41	Down, „ „ , „ „
—	—	—	6.0	40	Up, Mixed „ , {Pass., 10 Cars. Goods, 5 Wags.
5.0	0.60	0.7	—	40	Down, Passenger „ 10 Carriages.
5.4	1.12	0.7	—	41	Up, Mixed „ , {Pass., 6 Cars. Goods, 6 Wags.
6.5	1.12	1.3	—	27	Down, „ „ , {Pass., 6 Cars. Goods, 9 Wags.
8.0	0.94	—	—	606	Up, Mixed „ , {Pass., 5 Cars. Goods, 10 Wags.
6.0	0.66		—	605	Down, „ „ , {Pass., 8 Cars. Goods, 8 Wags.
3.5	0.81	—	7.0	608 and 2, in series.	Up, Passenger „ , 18 Carriages.
5.5	0.76	—	—	634	Down, Mixed „ , {Pass., 6 Cars. Goods, 20 Wags.
3.4	0.79	—	—	640	„ , Passenger „ , 17 Carriages.
12.4	0.74	—	—	610 and 113, in series.	Up, Mixed „ , {Pass., 6 Cars. Goods, 10 Wags.
—	—	—	—	Two workmen running going and returning.	—

TABLE II.

River.	Bridge Girder or Truss.	Deflection.			Vertical Vibration.	
		Instrumentally measured. (mm)	Directly measured (mm)	Mean. (mm)	2a (mm)	T (s)
Ōi (Kanaya) (Gov. Ry.)	200′ Double Warren Girder (No. 10 Girder)	—	—	—	4.0	0.40
		—	—	—	2.4	0.42
,,	200′ ,, (No. 14 Girder)	—	15.0	—	—	—
		—	14.8	—	—	—
Kizu (Kasagi) (Kwansei Ry.)	200′ Pratt Truss	18.2	—	—	7.3	0.43
		15.8	—	—	1.7	—
		—	—	—	5.3	0.37
		17.6	—	—	4.4	0.34
		17.4	—	—	6.1	0.31
		19.2	—	—	4.8	—
		17.0	—	—	4.5	0.37
,,	200′ ,,	—	—	—	4.5	0.37
		—	—	—	6.0	0.37
		—	—	—	5.1	0.41
		—	—	—	6.9	0.43
		—	—	—	6.8	0.42
		—	—	—	2.5	0.29
No. 3 Aizawa (Oyama) (Gov. Ry.)	200′ Bow-string Truss	—	—	—	2.2	0.36
		—	—	—	3.5	0.26
		—	—	—	4.5	0.38
,,	200′ ,,	—	10.5	—	—	—
		—	13.0	—	—	—
		—	11.8	—	—	—
		—	11.6	—	—	—
		—	11.3	—	—	—

CONT.

Transverse Vibration.		Longitudinal Vibration.	Time taken by Locomotive in passing over the girder or truss. (s)	No. of Locomotive.	Train.
2a (mm)	T (s)	2a (mm)			
5.8	—	—	—	608	Up, Goods Train, 24 Wagons
6.8	0.88	—	—	612	Down, „ „ , 18 „
—	—	—	—	608	Mixed „ , Pass., 6 Cars. Goods, 4 Wags.
—	—	—	—	512	Down, Goods „ , 12 Wagons.
—	—	—	6.0	35	„ , „ „ , 11 „
—	—	—	4.7	33	„ , Passenger „ , 12 Carriages
—	—	—	5.4	30	Up, „ „ , 11 „
—	—	—	4.7	35	„ , Goods Train, 11 Wagons
—	—	—	5.6	31	Down, Pass. „ , 10 Carriages
—	—	—	4.7	36	„ , „ „ , 10 „
—	—	—	6.0	38	„ , Mixed „ , Pass., 1 Cars. Goods, 11 Wags.
2.3	0.65	1.4	—	29	Up, Passenger „ , 11 Carriages
3.1	0.71	1.6	—	83	Down, „ „ , 16 „
1.2	0.61	1.3	—	38	„ , Goods „ , 6 Wagons
2.3	0.26	1.3	—	33	Up, Passenger „ , 11 Carriages
2.7	0.45	1.0	—	38	„ , Goods „ , 8 Wagons
1.9	0.77	1.5	—	35	Down, Pass. „ , 10 Carriages
—	—	—	5.6	272	Up, Passenger „ , 9 Carriages
—	—	—	5.3	188 and 200, in series.	„ , Goods „ , 28 Wagons
—	—	—	6.6	187 and 191, in series.	„ , Passenger „ , 18 Carriages
—	—	—	—	272	
—	—	—	—	183	
—	—	—	—	200	
—	—	—	—	278	
—	—	—	—	203	

TABLE II.

River.	Bridge Girder or Truss.	Deflection.			Vertical Vibration.	
		Instrumentally measured. (mm)	Directly measured (mm)	Mean (mm)	2a (mm)	T (s)
Tone (Toride) (Nippon Ry.)	200′ (Double Warren Girder) (1st Girder from Tokyo side)	—	17.5	—	—	—
		—	25.4	—	—	—
		—	23.5	—	—	—
„ „	200′ (Double Warren Girder) (2nd Girder from Tokyo side)	—	—	—	2.6	0.35
		—	—	—	4.0	0.46
		—	—	—	5.6	0.43
		—	—	—	4.5	0.44
„ „	200′ („)	—	—	—	8.5	0.40
	(„)	—	—	—	4.5	0.50
		—	—	—	7.3	0.41
No. 3 Sakawa (Yamakita.) (Gov. Ry.)	200′ (Bow-string Truss)	—	—	—	4.5	0.34

CONT.

Transverse Vibration.		Longitudinal Vibration.	Time taken by Locomotive in passing over the Girder or Truss. (s)	No. of Locomotive.	Train.
2a (mm)	T (s)	2a (mm)			
—	—	—	—	123	Down, Goods Train.
—	—	—	—	527	Up, Mixed ,,
—	—	—	—	211 and 510, in series.	Down, ,, ,,
3.1	—	0.5	—	555	,, , Goods Train.
5.5	0.93	1.0	—	515	Up, Mixed ,,
4.6	1.00	0.7	—	513	Down, ,, ,,
4.7	0.91 0.45	0.7	—	553	Up, Goods ,,
4.8	0.86	0.7	—	123	Down, ,, ,,
5.0	0.90	1.0	—	527	Up, Mixed ,,
6.8	1.20	0.7	—	211 and 510, in series.	Down, ,, ,,
5.5	0.39	3.4	—	190 and 272, in series.	Up, Passenger ,,

TABLE III.—SUMMARY OF THE DEFLECTION AND VIBRATION MEASUREMENTS.

Bridge Girder or Truss.	Deflection		Vertical Vibration				Transverse Vibration				Longitudinal Vibration	
			Max. 2a		T		Max. 2a		T			
	2a	Mean	Absolute	Mean	Longest	Mean	Absolute	Mean	Longest	Mean	Max. 2a	Mean
	(mm)	(mm)	(mm)	(mm)	(s)	(s)	(mm)	(mm)	(s)	(s)	(mm)	(mm)
*Tone (Toride) 20′ Plate Girder	2.9	2.5	—	—	—	—	—	—	—	—	—	—
* „ 60′ „ „	11.1	9.9	1.5	1.2	0.26	0.23	—	—	—	—	—	—
*Kuji (Ōmika) 60′ „ „	12.5	12.4	—	—	—	—	—	—	—	—	—	—
Tone (Maebashi) 70′ „ „	9.9	8.8	2.0	1.9	0.22	0.20	5.0	3.4	0.43	0.38	1.0	0.4
*Kizu (Kasagi) 70′ „ „	16.3	15.4	—	—	—	—	—	—	—	—	—	—
*Kuji (Ōmika) 100′ Warren	17.8	16.2	5.6	4.8	0.35	0.34	10.0	9.5	1.06	0.82	0.9	0.7
*No. 2. Sakawa (Yamakita) 100′ „	14.7	13.2	5.0	4.0	0.35	0.31	10.2	7.5	1.09	0.93	2.7	2.0
*No. 3. „ („) 100′ „	15.4	—	5.1	—	0.29	—	—	—	—	—	—	—
Kizu (Kasagi) 100′ „	14.0	10.9	4.7	3.1	0.30	0.27	–					
„ („) 100′ „	10.2	10.0	—	—	—	—	—	—	—	—	—	—
Ibi (Nagashima) 120′ Pratt	8.0	6.5	1.6	1.3	0.28	0.25	—	—	—	—	—	—
*No. 3. Aizawa (Oyama) 105′ Pratt Deck	25.4	23.9	5.8		0.33	0.32	—	—	—	—	—	—
„ („) „ „ „	17.5	16.3	—	—	—	—	—	—	—	—	—	—
Kami-Usui (Matsuida) 105′ „ „	20.2	17.1	9.2	5.8	0.37	0.30	15.0	8.7	1.48	1.10	1.5	0.9
Ibi (Nagashima) 200′ Double Warren	18.5	17.1	8.2	4.1	0.59	0.43	6.5	5.6	1.12	0.95	1.3	0.9
*Oi (Kanaya) 200′ „ „	25.1	18.5	7.2	3.9	0.42	0.39	12.4	6.5	0.94	0.80	-	—
„ „ „ „ „	15.0	14.9	—	—	—	—	—	—	—	—	—	—
*Tone (Toride) 200′ „ „	29.5	24.1	—	—	—	—	—	—	—	—	—	—
* „ („) „ „ „	-	—	8.5	5.3	0.50	0.43	6.8	5.0	1.20	0.97	1.0	0.8
Kizu (Kasagi) 200′ Pratt Deck	19.2	17.5	7.3	5.1	0.43	0.37	3.1	2.3	0.77	0.69	1.6	1.4
*No. 3. Sakawa (Yamakita) 200′ Bow String	—	—	-	4.5	—	0.34	—	5.5	—	0.39	—	3.4
*No. 3. Aizawa (Oyama) 200′ „ „	—	—	4.5	3.4	0.38	0.83	—	—	—	—	—	—
* „ („) „ „ „	13.0	11.6	—	—	—	—	—	—	—	—		—
Hozu (Saga)‡ 200′ „ „	—	—	3.7	3.3	0.39	0.38	2.7	—	0.97	0.90	1.3	0.9

‡ The Hozu-*gawa* bridge vibrations were measured by Professors S. Tanabe and T. Hibi, of Kyoto Imp. Univ.

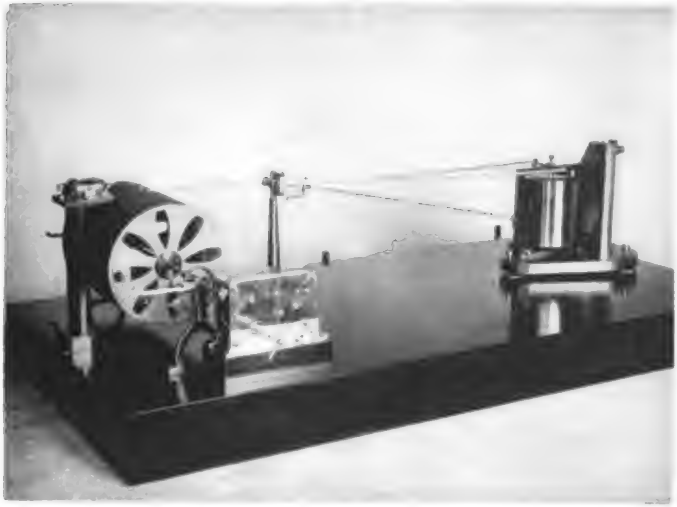
From Table III, we see that the absolutely greatest amount of the deflection reached 29.5 mm in the case of one of the 200′ double Warren girders of the Tone-*gawa* (Toride) bridge, and the next greatest amount of 25.4 mm occurred in the case of one of the 105′ Pratt *deck* truss of the No. 5 Aizawa-*gawa* bridge; each having taken place under the passage of two tender engines in series. The greatest vertical vibration of 9.2 mm, which occurred in the case of the Kami-Usui-*gawa* 105′ truss, similar to that of the last-named bridge, was produced by the passage at a velocity of 17 miles / hour of an Abt engine of 53t 12c coupled to a break-van; the maximum vertical motion of a girder or truss of long span generally occurring with a train running at a comparatively slow speed. The next greatest vertical vibration of 8.5 mm occurred in the case of the first-mentioned Tone-*gawa* bridge. From these figures it will be readily understood that the vertical vibration forms an element of the bridge motion of a considerable importance. The period of the vibration varied from about 0.2 sec. for 60′–70′ plate girders to nearly 0.6 sec. for the 200′ double Warren girders.

The two greatest transverse vibrations of 15.0 and 12.4 mm occurred respectively in the cases of the Kami-Usui *gawa* 105′ deck Pratt truss and one of the 200′ double Warren girders of the Ōi-*gawa* bridge; the vibration period of former bridge reaching an extraordinary length of nearly 1½ sec. The length of the transverse period was generally more than double the vertical period.

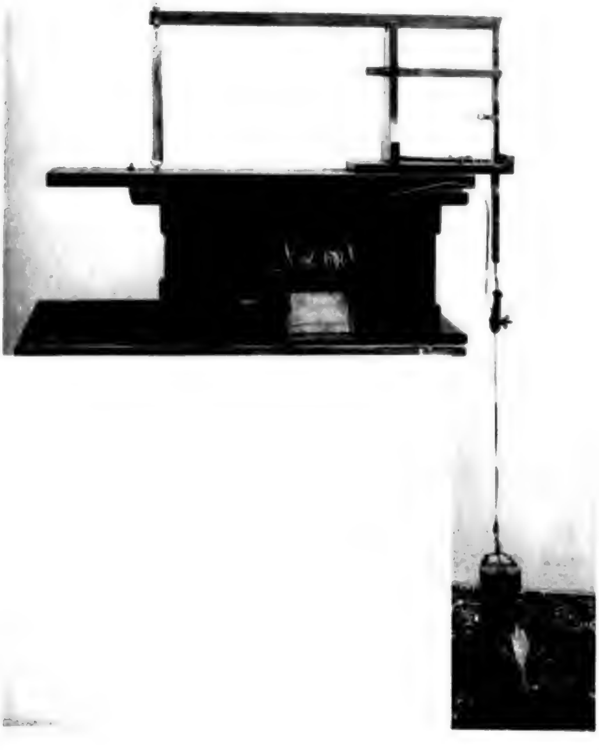
The longitudinal vibrations were always very quick, and was not able to satisfactorily measure their periods with the instruments then used. The amplitude of these movements was small, varying between 0.9 and 2.7 mm for the different girders and trusses. In virtue of the great intensity or violence, the longitudinal motion, although small, must play an important part in the process of loosening the rivets, or wearing the joints, and its study will prove of great value in connection with the strength of the bridge structures.

A careful study of the results of the measurements given in Tables II and III will disclose many interesting points. Amongst others, it will be observed that a weak bridge has a larger range (double amplitude) as well as a longer period than a strong bridge, the vibration elements being, so to speak, the indices of the strength or quality of a given elastic structure.

A Horizontal Tremor-Recorder.



Deflection Measurer.



Horizontal Tremor Recorder.

By

F. Omori, Sc., D.,

Member of the Imperial Earthquake Investigation Committee.

In the *Publications*, No. 18, I have described a form of horizontal tremor recorder designed to measure the small vibrations of the ground due to artificial causes. Since then several instruments of the same type, adapted to a continuous seismic registration, have been constructed, the two horizontal component vibrations being written on a smoked paper wrapped round a revolving cylinder in the usual way. These seismographs, with a magnification of about 100, set up in the Mount Tsukuba and Osaka Meteorological Observatories proved very useful in the observation of near earthquakes, or those, say, of the epicentral distance under 1000 km.

The upper picture on Pl. XLII represents a single component "tremor recorder," whose heavy bob is 32 kg in weight, and which magnifies the motion 200 times.

Although the observation of the teleseismic disturbance is very important, it must not be forgotten that the chief interest of the earthquake measurements is in connection with the study of local shocks. For an earthquake country it will be more to the purpose to provide the different stations with the "tremor recorders," or similar instruments, together with ordinary seismographs for the observation of the macro-seismic disturbance; the instruments for the study of the teleseismic motion being set up only at a few standard observatories.

Long Period Horizontal Pendulum.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

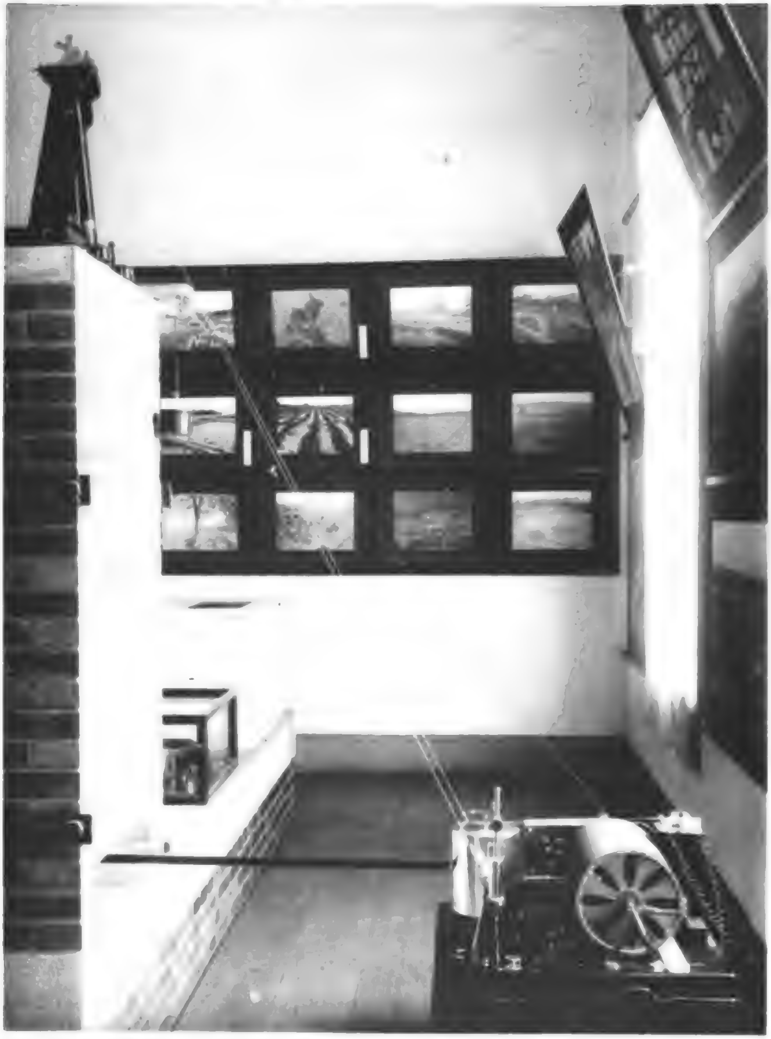
For the observation of slow vibrations occurring in the teleseismic motion it is necessary to bring the "steady mass" of a seismograph sufficiently near to the state of neutral equilibrium, so as to make the natural oscillation period of the instrument much longer than that of the earthquake movements. In the case of a horizontal pendulum, this amounts to minimizing the angle, φ, formed between the vertical and the axis of the pendulum, or the line joining the points of support and of suspension of the latter. Now, as the tendency of the pendulum to become unstable depends on the smallness of the horizontal distance between the points of support and of suspension, we can, by increasing the vertical distance between these two points, lessen the angle φ and thereby increase the oscillation period, without throwing the pendulum out of the stable condition. If the length of the horizontal strut be about 1 metre, and the vertical height of the pendulum be $2\frac{1}{2}$ to 3 metres, the oscillation period can be raised to about 3 min.*; the mass of the heavy bob employed being about 50 kg.

Pl. XLIII represents a horizontal pendulum, temporarily set up in the Seismological Laboratory; the instrumental constants being as follows:—

---

* See also the *Publications*, No. 4.

A Long-period Horizontal Pendulum.



Weight of the bob=50 kg.
Length of the horizontal strut=1 metre.
Vertical height of the pendulum=2 metres.
Pointer multiplication=30.

The pendulum can be adjusted without difficulty to an oscillation period of about $2^m\ 15^s$.

The recording apparatus has received a notable improvement in the hand of H. I. H. Prince Yamashina, who takes a keen interest in meteorological and seismological observations. The mechanism is so arranged that the cylinder can be quietly rolled away horizontally and normally to its axis, enabling us to take off or put in the position the record-receiver without affecting the writing pointer.

Seismographic Diagrams of the Local Earthquake of June 11, 1907.[*]

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. Area of Disturbance. The earthquake of June 11, 1907, at $8^h\ 59^m\ 21^s$ a.m. (Hongō, Tokyo) was felt moderately or strongly in the vicinity of Tokyo over an area about 200 km in length and about 100 km in width. The area, within which the motion was sensible, stretched from near the northern end of the Main Island to the vicinity of Osaka, over a distance of nearly 900 km. (See Fig. 1, Pl. XLIV.) In Tokyo, the earthquake was of a moderate intensity, and, although no damage was caused, it was the strongest next to the severe shock of Feb. 24, 1906.

2. Position of the Eqke Origin. The durations of the preliminary tremor at Tokyo, Mito, and Mount Tsukuba, were respectively 8.5 sec., 9 sec., and 7.2 sec. The circles drawn about these places and centres with radii equal to the corresponding epicentral distances[‡], meet each other near the origin of disturbance, whose approximate position is $\lambda=140°45'$, $\varphi=35°30'$, at about 100 km to S78°E of Tokyo. (See Fig. 1.) In Tokyo, the shock was preceded by a slight, but distinct sound.

3. Microseismograph Records. Figs. 2, 3, and 4 (Pl. XLV) give the EW, vertical, and NS component diagrams furnished by the respective microseismographs. The instrumental constants are:—

---

[*] The times are given in the 1st Normal Japan Time, namely, that of 135° E.

[‡] Calculated according to the formula $x^{\text{km}}=7.27\ y^{\text{sec.}}+38^{\text{km}}$, where x is the epicentral distance and y is the duration of the total preliminary tremor.

EW............Multiplication = 10; Pendulum period = 28 sec.
Vertical ...... „ = 12; „ = 4 „
NS .... „ = 30; „ = 48.5

It will be observed that the preliminary tremor was suddenly followed by the maximum vibration, the two displacements of the latter being as follows:—

1st motion = 5.1 mm, towards S70°E;
2nd „ = 6.6 „ (maximum), towards N65°W.

Thus the very first displacement of the principal portion took place approximately towards the earthquake origin, while the counter, or maximum, displacement was directed away from the latter. The vibration in question belongs evidently to the "longitudinal wave," its mean direction of S67°E—N67°W being not much different from the epicentral direction from Tokyo. For the next $1^m 20^s$, the motion remained active, the total duration being about 20 min. The comparative shortness of the duration, in spite of the large amplitude of the principal vibration, is the characteristic of a local shock.

For the sake of comparison, I give in Fig. 4 (Pl. XLV) the EW component diagram of the moderate earthquake of June 23, 1902, at $7^h 42^m 42^s$ A.M., recorded at Hongō by the same instrument as in Fig. 2. It will be observed that Figs. 2 and 4 are almost perfectly identical to one another; the two displacements composing the maximum vibration at the commencement of the principal portion of the earthquake here considered being respectively 5.7 mm towards E, and 7.0 mm towards W.

Figs. 6, 7, 8, and 9 (Pl. XLVI) are the EW component diagrams of the earthquake (June 11, 1907) furnished by horizontal pendulums, as follows:—

Figs. 6 ..Hongo (Tokyo). Multiplication=30; Pendulum period=41.5 sec.
Figs. 7... „ („) „ =15; „ =61.5 „
Figs. 8...Hitotsubashi(„) „ =10; „ =31.1 „
Figs. 9...Mito. „ =20; „ =28.8 „

4. Macroseismograph Records. Fig. 10, Pl. XLVII, is the record furnished by a Gray Milne type macroseismograph, set up in the Seismological Institute, the magnification of the EW, NS and vertical components being respectively 5, 5, and 8. The numerals, 1, 2, 3, and 4, indicate corresponding epochs in the three components. The duration was in this case, about 6 min. The large movement at the commencement of the principal portion was as follows:—

Resultant hor. motion=6.8 min., towards N50°W.
Vertical motion =0.8 mm upwards.

This result is nearly similar to that indicated by the microseismographs (§3). Only the first displacement, corresponding to a single amplitude, is here very imperfectly shown, on account of the length of its period and the friction of the instrument. The subsequent and principal macro-seismic vibrations* were as follows:—

Max $2a=1.6$ *mm*, $T=1.6$ sec.
„ „ , $T=0.72$ „

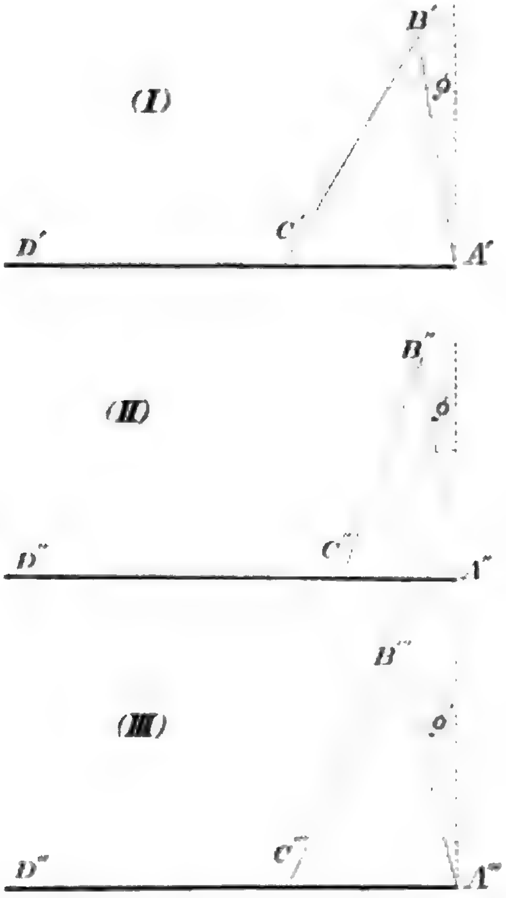
The period of the "ripples," or small sharp vibrations, was 0.20 sec.

Fig. 11 (Pl. XLVIII), is the macroseismographic record obtained at Hitotsubashi (Tokyo), the EW, NS, and vertical components being multiplied 3, 4, and 2 times, respectively.

---

* T and $2a$ denote as usual the complete period and the double amplitude, respectively.

The numerals, 1, 2, 3, and 4, indicate corresponding epochs in the three components. It will be observed that the movements of the macroseismic character at Hitotsubashi is more regular and much greater than at Hongo; this being the consequence of the extreme softness of the ground at the former place.



5. Tiltometer Records. The following is the principle of the experiments made to test the existence or non-existence of tilting in the ordinary or macroseismic motion, which I have carried on since 1897 at the Seismological Institute. As diagrammatically shown in the accompanying figure, let there be three horizontal pendulums, I, II, and III, in which C', C'', C''' are the heavy bobs; B'C', B''C'', B'''C''' the ties; A'C', A''C'', A'''C''' the struts; and C'D', C''D'', C'''D''' the writing pointers; the lengths A'D' and A''D'' being equal to one another. Further, let the two pendulums, I and II, have a common angle (=φ) of inclination of the pendulum axis to the vertical, the ratios of multiplication $\frac{A'C'}{C'D'}$ and $\frac{A''C''}{C''D''}$ being unequal; while the two pendulums, I and III, have equal ratios of multiplication, $\frac{A'C'}{C'D'}$ and $\frac{A'''C'''}{C'''D'''}$, but unequal angels of inclination of the pendulum axes, φ and φ'. The three pendulums are placed with their planes parallel to one another. Thus the first two pendulums would have an equal sensibility for a tilting motion, but different magnifications for a horizontal motion; while the first and third pendulums have an equal magnification for a horizontal motion, but different sensibilities for a tilting motion.

Fig. 12 (Pl. XLIX) is the record of the EW component motion obtained on the occasion of the earthquake of June 11, 1907, by one of the machines composed, according to the principle above explained, of the three pendulums A, B, and C, the instrumental constants being as follows:—

Pendulum.	Length of Strut.	Total length of Strut and Pointer.	Multiplication (for Hor. Motion)	T_0	T	$\varphi = \frac{T_0^2}{T^2}$
	cm	cm		sec.	sec.	
A	12	48	4	0.70	4.36	$\varphi_A = \varphi_B$
B	7	48	7	0.51	3.31	$\varphi_B = \varphi_A$
C	7	28	4	0.53	2.50	φ_C

In the above table T_0 and T denote respectively the complete period of vibration of each pendulum when suspended vertically and when actually set up as a horizontal pendulum. The displacement of the writing index of the pointer corresponding to a tilting α is, in each case, given by the formula.

$$\gamma\ (\text{sensibility}) = l \times \frac{\alpha}{\varphi}\,.$$

From the adjustments of the three pendulums as given in the above table, we arrive at the following relations:—

$$\varphi\ (\text{for } \boldsymbol{C}) = 1.74\ \varphi\ (\text{for } \boldsymbol{A} \text{ and } \boldsymbol{B}).$$

$$\gamma\ (\text{for } \boldsymbol{A} \text{ and } \boldsymbol{B}) = 3\gamma\ (\text{for } \boldsymbol{C}).$$

Thus the two pendulums *A* and *B* ought to give, for a tilting of the ground, a record three times larger than the pendulum C;

while each of the two pendulums *A* and *C* gives, for the horizontal motion, a record equal to 4/7 of that of the pendulum B.

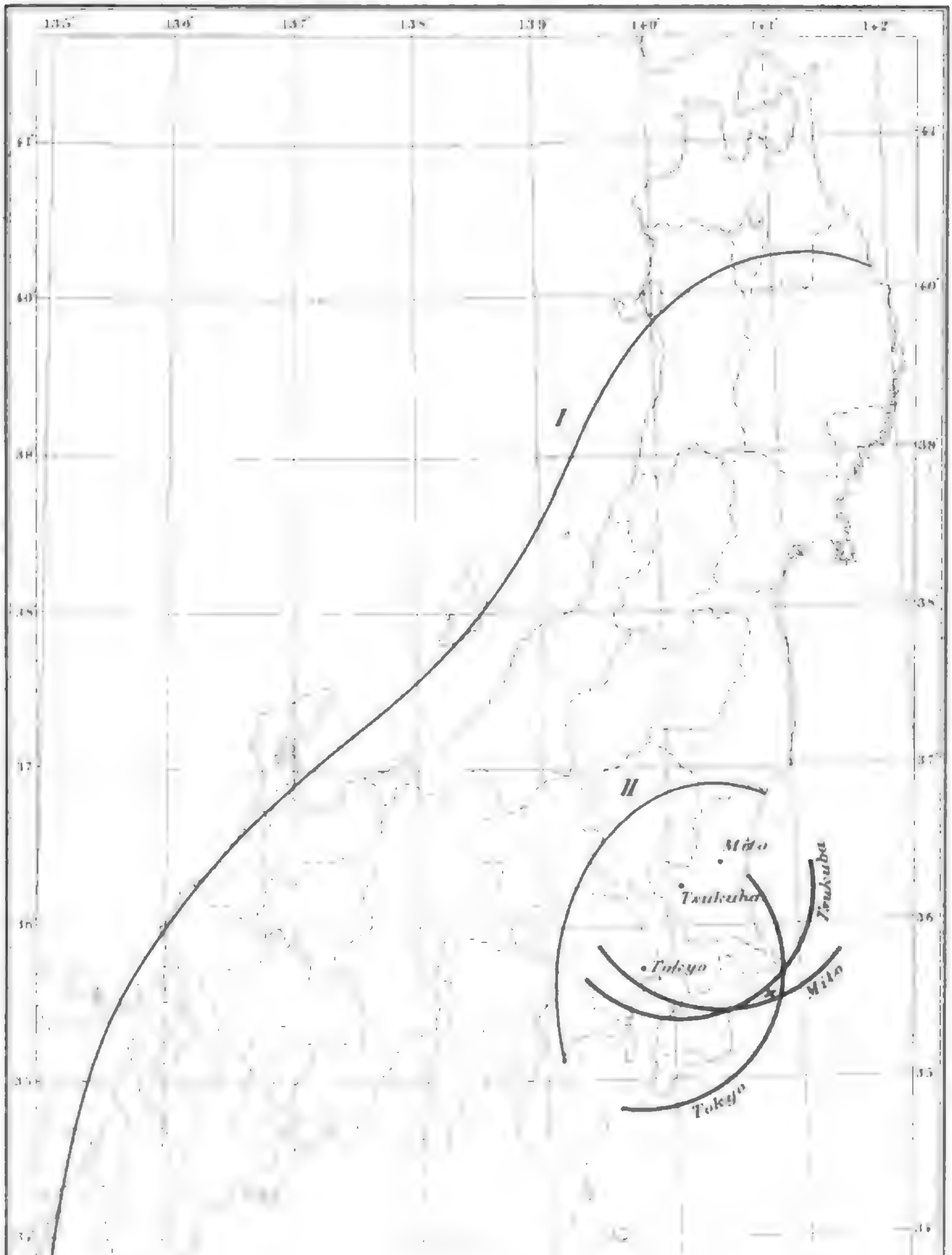
Although different amounts of the friction in the three pendulums evidently interfered to some extent with the accuracy of the records, Pl. XLIX indicates, as well as the diagrams obtained on other occasions, that the tilting element in the ordinary earthquake motion is, if any, very slight in amount.*

---

[*] The First Report on this experiment was published in No. 32 of the Japanese *Reports* of the Imp. Earthquake Inv. Comm. ([illegible]).

Fig. 1. Earthquake of June 11, 1907.

(×)............Eqke Origin.
(I) ....Boundary of Area of Sensible Motion.
(II) .... „ „ „ Strong or Moderate Motion.


135°
136°
137°
138°
139°
140°
141°
142°
41°
40°
39°
38°
37°
36°
35°
34°
I
II
Mito
Tsukuba
Tokyo
Tsukuba
Mito
Tokyo

Figs. 2, 3, and 4. Earthquake of June 11, 1907. Observed at Hongo, Tokyo.

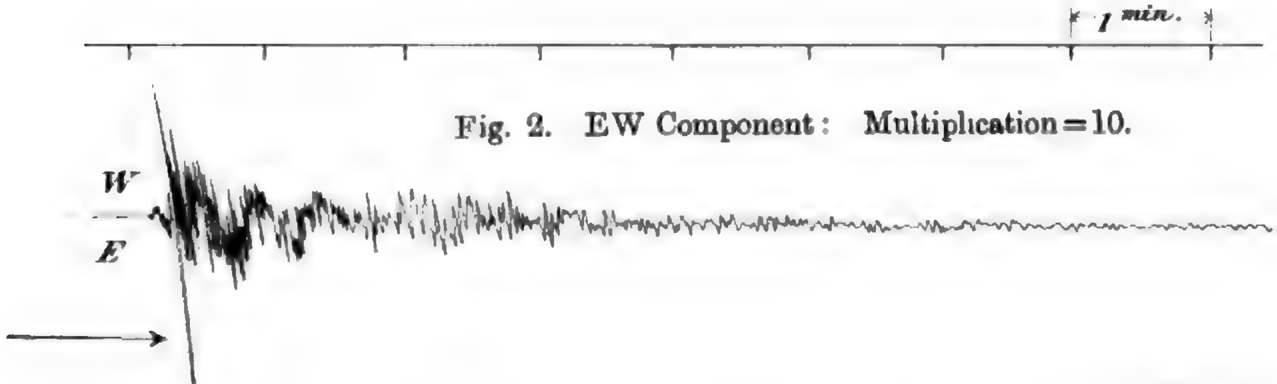


Fig. 2. EW Component: Multiplication=10.

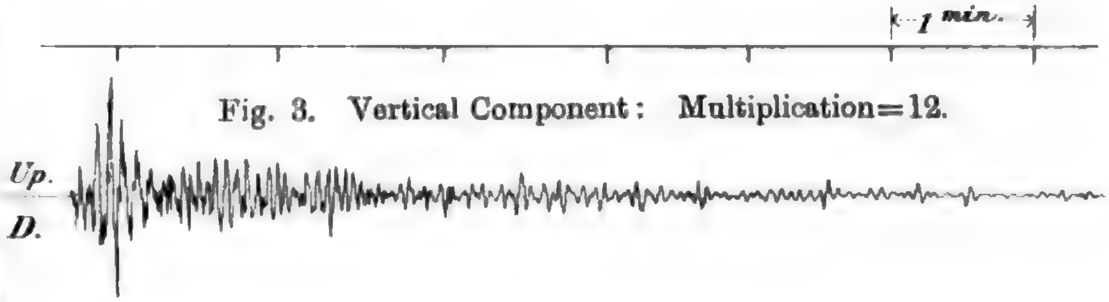


Fig. 3. Vertical Component: Multiplication=12.

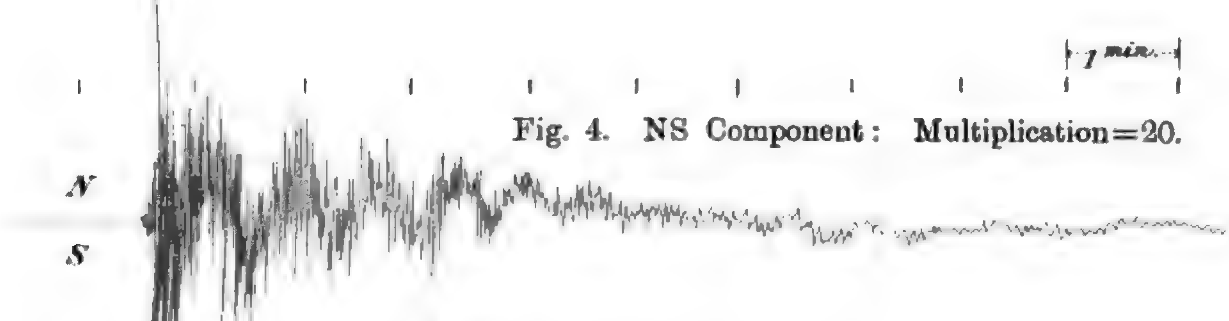


Fig. 4. NS Component: Multiplication=20.

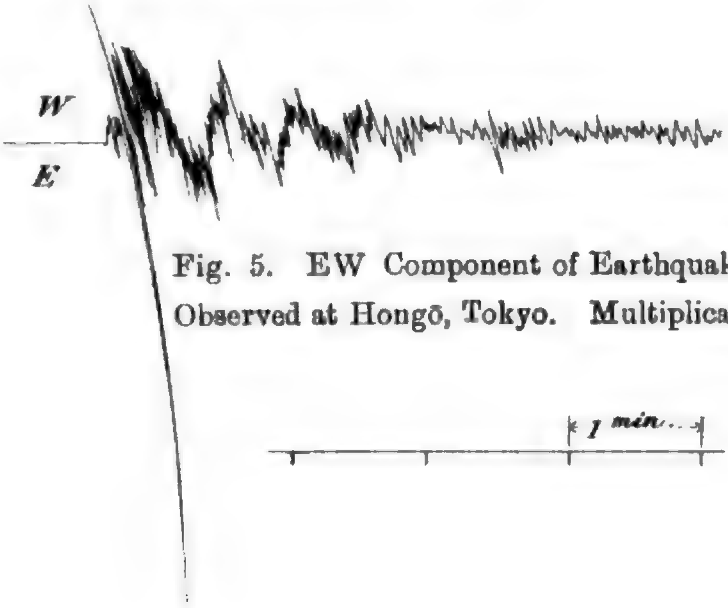


Fig. 5. EW Component of Earthquake of June 23, 1902. Observed at Hongō, Tokyo. Multiplication=10.

Horizontal Pendulum Diagrams of Eqke of June 11, 1907.

Fig. 6. EW Component, Hongō.
Multiplication=30.

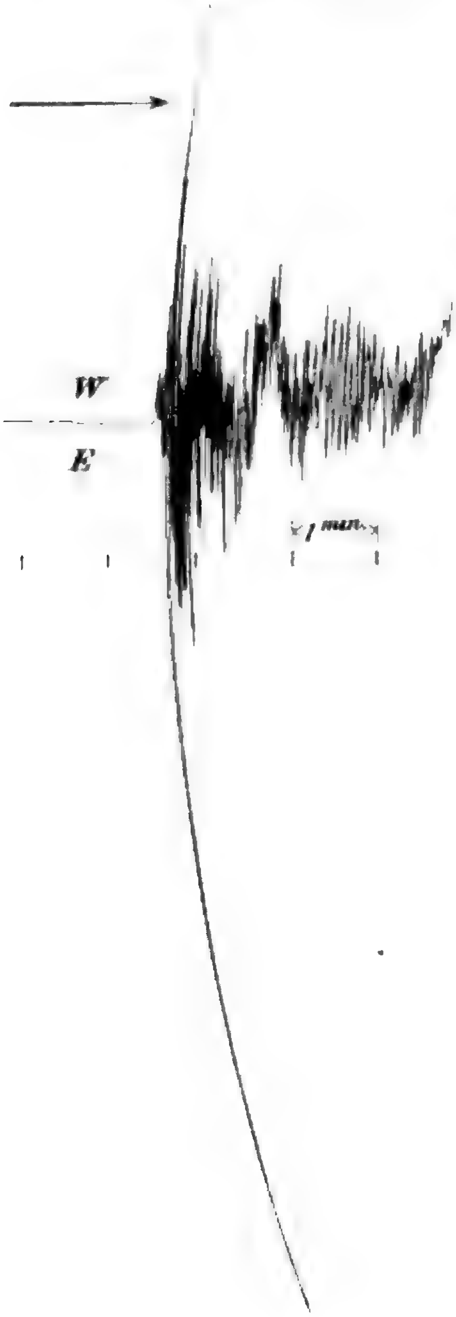


Fig. 7. EW Component, Hongō.
Multiplication=15.

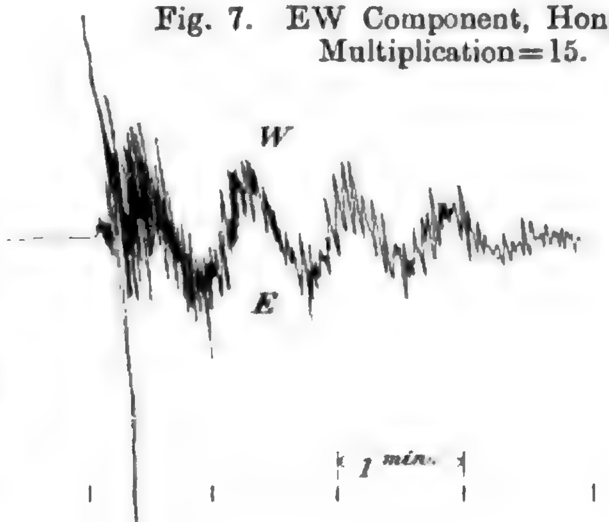
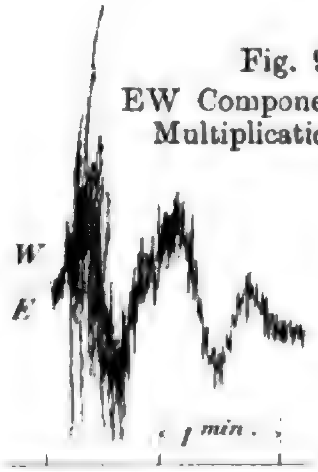


Fig. 9.
EW Component, Mito.
Multiplication=20.



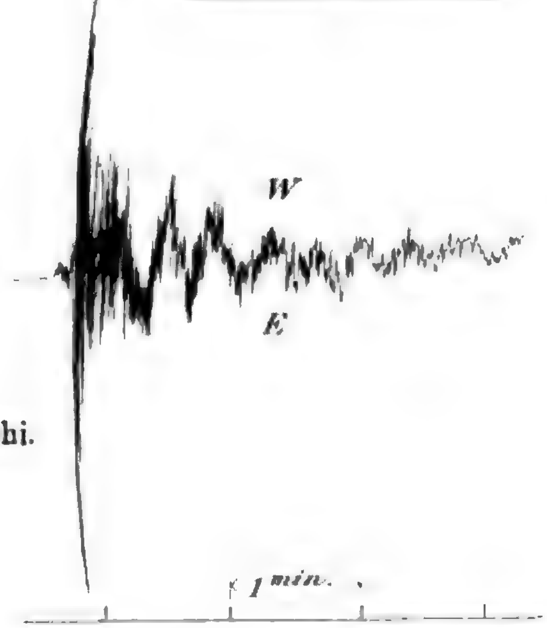


Fig. 8. EW Component, Hitotsubashi.
Multiplication=10.

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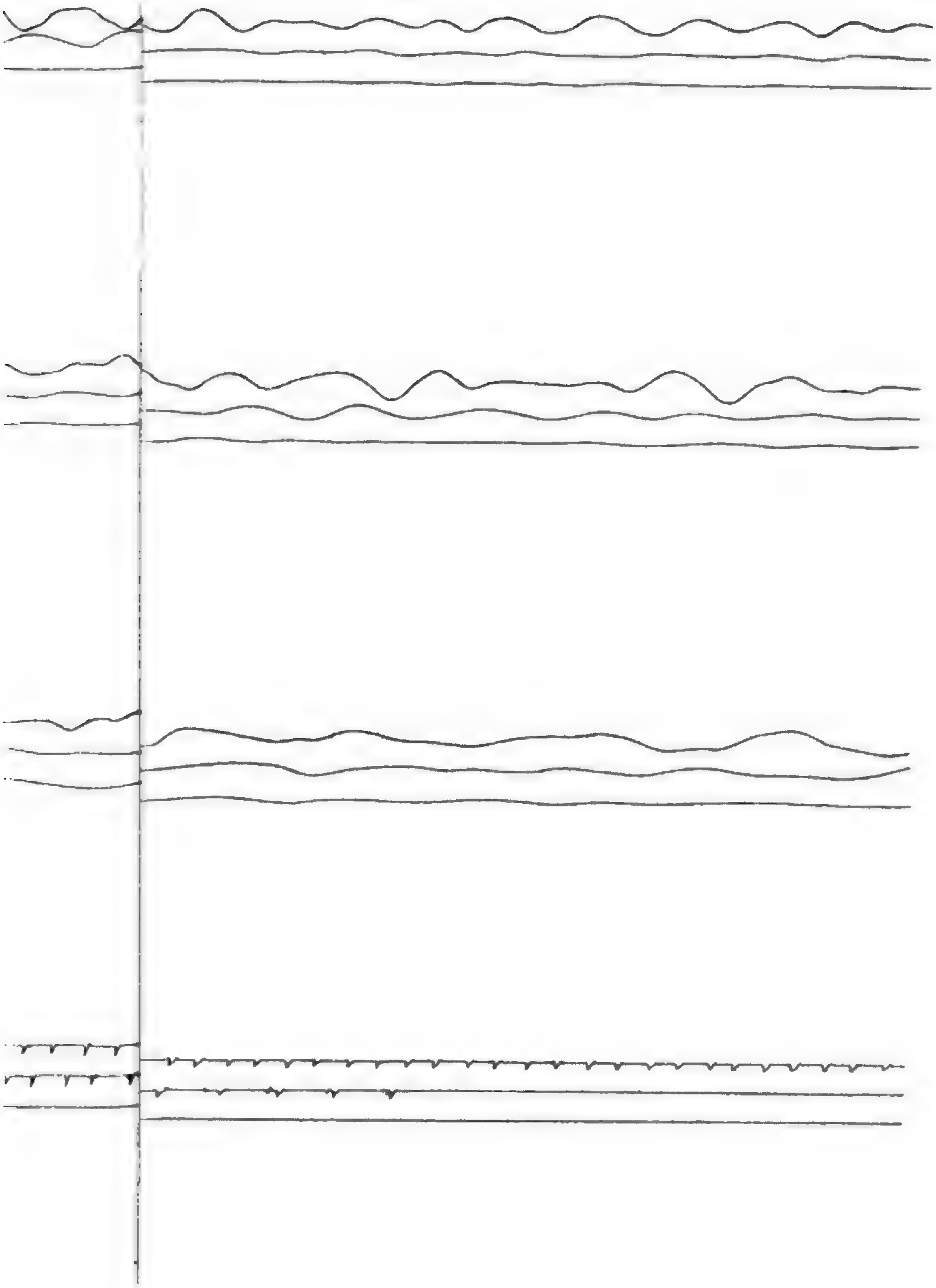

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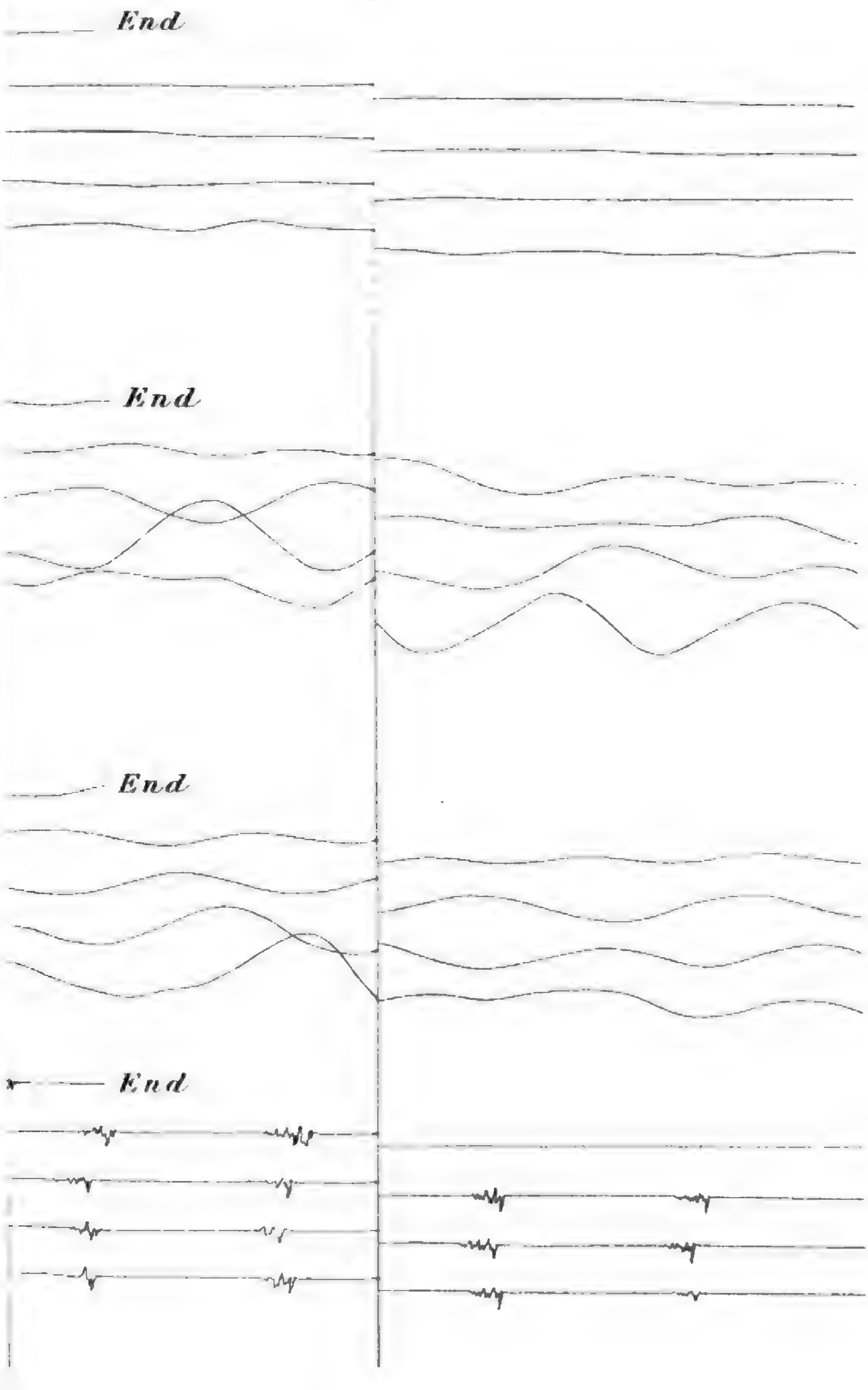

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PL. XLIX.

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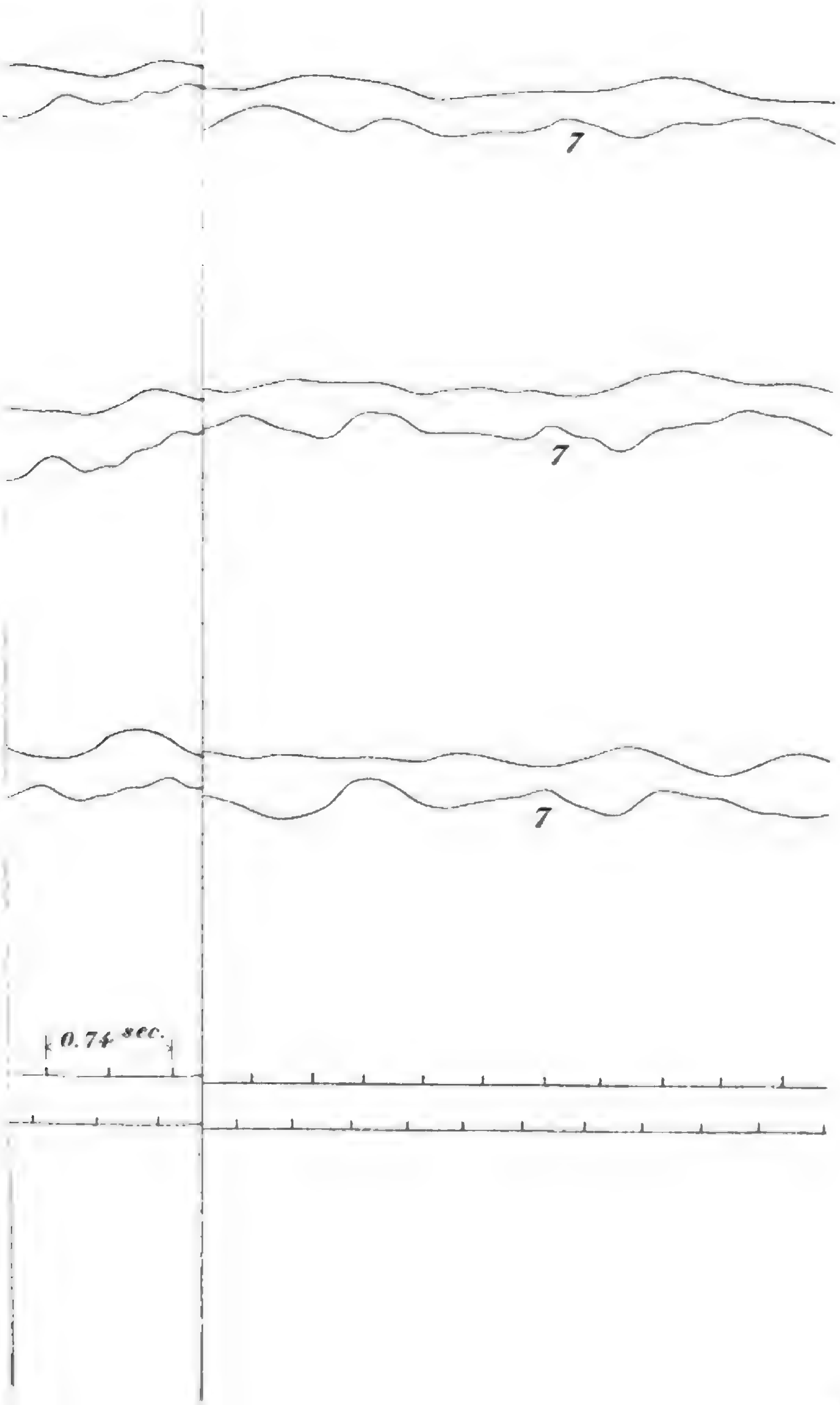
……… ,, = 7
……… ,, = 4



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TOKYO. 1908.

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On Micro-tremors.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. I-III.

Introduction. The non-seismic vibrations of the ground called "pulsatory oscillations" are small slow movements with periods generally of about 4 or about 8 sec., possibly all over the world. These oscillations, which are most markedly shown at Tokyo, Osaka, and other places situated on an extensive plane of new formation, and also probably at mid-ocean islands[*], have sometimes a double amplitude of 0.5 mm or more. What I propose here to term *micro-tremors* are those insensible movements of the ground, whose period is usually less than 1 sec., and whose amplitude is much smaller than that of the pulsatory oscillations. In short, the micro-tremors are, whatever their origin may be, extremely minute vibrations of a nature similar to that of the movements composing the macro-seismic, or sensible, part of the earthquake motion proceeding from a near centre of disturbance.

The diagrams furnished by Omori horizontal tremor recorders and tromometers[‡], of 90 to 300 times magnifications, set up in

---

[*] As shown by the Omori Hor. Pend. Tromometer observation at the meteorological observatory of Hachijo-jima, an island belonging to the Fuji volcanic chain.

[‡] These instruments are improved forms of those described in the *Publications*, No. 18, and the *Bulletin*, Vol. I, No. 4.

Osaka and Tokyo indicate the micro-tremors often quite distinctly. For the sake of clearness, however, some photographic enlargements of the original records are reproduced in Pls. I to III. I give next the results of some preliminary investigations on micro-tremors.

Observation at Hitotsubashi (Tokyo). The observation at Hitotsubashi was made with a horizontal pendulum tromometer of 100 times magnification. The maximum double amplitude in the EW component was about 0.0015 mm, the average periods' each deduced from 100 consecutive vibrations, being as follows :—

Date (1907).		Average Period (EW Component).	
July	5-6	0.80 sec.	....*Mean*, **0.83** sec.
„	„	0.91	
„	„	1.01	
Oct.	29-30	0.84	
„	30-31	0.83	
„	„	0.82	
Nov.	22-23	0.77	
„	„	0.88	
„	28-29	0.60	
„	„	0.82	

The mean period of micro-tremors at Hitotsubashi is thus seen to be 0.83 sec. To compare these tremors with the quick vibrations actually occurring in an earthquake, I give in Pl. I a part of the tromometer record for July 5 and 6, 1907, which was photographically enlarged 8 times and thus magnifies 800 times the movements of the ground, with a time scale of 197.4 mm for

1 minute. The seismic disturbance shown in the diagram consists of the preliminary tremor and the earlier part of the principal portion of the earthquake of July 6, 1907, which originated under the sea about 900 km to the NE of Tokyo and was felt strongly at the coast of Nemuro and Kushiro (Hokkaido). In Tokyo, the shock was slight, and the total duration about 2 hours, the time of occurrence being 0h 48m 07s A.M. According to Pl. I, the quick vibrations in the preliminary tremor, which lasted 90.0 sec. (the commencement is marked *a*), were as follows* :—

Average $T=0.77$ sec., Max. $2a=0.074$ mm.

The active vibrations at the commencement (marked *b*), of the principal portion was as follows :—

Average $T=0.88$ sec., Max. $2a=0.36$ mm.

Thus the mean period of the macro-seismic movements was in this case about 0.83 sec., which happens to be identical with the average period of the micro-tremors (at Hitotsubashi) as given in the foregoing table. Especially, the larger and slower ones of these tremors, as those marked *e* and *f* (Pl. I), will be seen to be similar in nature to the prominent vibrations occurring in the principal portion (*b*) of the earthquake. Finally, for the sake of reference, I may state that, according to the result of the macro-seismic measurement in Tokyo‡, the average period at Hitotsubashi was found to be 0.77 sec., this characterizing the ordinary earthquake vibrations. The period of strong shocks at the same place is a little longer and equal to 0.9 to 1.0 sec.

Observation at Hongo (Tokyo). The micro-tremors at Hongo are probably somewhat smaller than those at Hitotsubashi, the max. 2a in the EW component being about 0.0011 mm. Pl. II is a part of the diagram for Jan. 23, 1908, furnished by an EW component horizontal tremor-recorder with an original pointer multiplication of 300 times, enlarged photographically 8 times, the resultant magnification being thus equal to 2,400, with a time scale of 835 mm for one minute. The average periods of the micro-tremors each deduced from 200 consecutive vibrations, were as follows :—

---

* T and $2a$ denoting as usual the complete period and the double amplitude, respectively.

‡ The "Publications," No. 11, p.p. 51 and 52.

Date (1908).		Average Period (EW Component).
Jan.	20-21	0.28 sec.
,,	22-23	0.28
,,	24-25	0.28
,,	,,	0.32
Mean............		**0.29** sec.

The mean value of the period of the micro-tremors was in these cases 0.29 sec., which is not much different from those of the quick vibrations and ripples occurring at Hongo in actual earthquakes. Thus, according to the macro-seismic measurement at Hongo*, we have the following results :—

Average period of max. quick horizontal vibrations = 0.26 sec.
,, superposed horizontal ripples = 0.20 ,,
,, max. quick vertical vibrations = 0.25 ,,

Observation at Osaka. The horizontal tremor-recorder with a multiplication of 90 times, at the Osaka Meteorological Observatory (Director, Mr. N. Shimono.) indicates micro-tremors much more distinctly than in Tokyo, the max. $2a$'s in the EW and NS components being each about 0.008 mm. Pl. III is a part of the record for Dec. 28, 1907, enlarged photographically 7.8 times, so that the resultant magnification is about 700 times. The average period of micro-tremors was as follows:—

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* See the *Publications*, No. 11, p.p. 53–55.

Date (1907).		Average Period*.			
		EW Component.		NS Component.	
Nov.	18–19	0.81 sec.	(100)	0.90 sec.	(100)
,,	,,	0.88	(100)	0.95	(100)
,,	21–22	0.77	(100)	0.88	(100)
,,	,,	0.80	(100)	0.84	(100)
Dec.	20–21	0.74	(200)	0.87	(200)
,,	21–22	0.68	(200)	0.89	(200)
,,	22–23	0.74	(200)	0.84	(200)
Mean..........		**0.76**		**0.88**	

The average period of the micro-tremors obtained by taking the mean from the two horizontal components is 0.82 sec. In this connection it is interesting to note that the ordinary seismograph observation at the same observatory of the vibrations caused by a powder explosion at a distance of 5 km in one of the suburbs of Osaka indicated also similar periods, as follows† :—

Vertical motion....Aver. $T=0.75$ sec. (Max. $2a=0.40$ mm);
EW ,, ... ,, $=0.83$,, (,, $=0.48$,,);
NS ,, ... ,, $=0.82$,, (,, $=0.24$,,);

the mean value of the period of the horizontal motion being thus

---

* The numbers of consecutive vibrations, from which the average period was deduced is in each case indicated by the figures 100 or 200, enclosed within brackets.

† An account of the vibrations caused by the powder explosion at Fuku-mura, near Osaka, is given by the present author in the Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 57.

0.82 sec. In the cases of the strong Inland Sea earthquake of June 2, 1905, and two of its after-shocks, the period of the maximum horizontal motion at Osaka was about 1.0 sec.

Conclusion. The micro-tremors at Tokyo and Osaka seem to occur chiefly during the day time, and may be due to traffic and other artificial causes, and also to the impact of winds against the ground. At any rate, however, their periods seem to be nearly identical with those of the ordinary sensible, or macro-seismic, vibrations at the respective places of observation, just as the period of the pulsatory oscillations are found to be similar to some component movements occurring in actual earthquakes. It is needless to remark that both pulsatory oscillations and micro-tremors form interesting subjects of study, especially in connection with local earthquakes.

Tokyo. Jan., 1908.

Note on the Tokyo Earthquake of Nov. 22, 1907.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. IV-VI.

The earthquake of Nov. 22, 1907, at 2h 17m A.M., was one of the strongest felt in Tokyo since the semi-destructive shock of June 20, 1894. The disturbance, which caused no damage, was a local one, and the severity of motion in Tokyo was partly due to the proximity of the latter to the earthquake origin. The total duration of the records furnished by the teleseismographs in Tokyo was only 24 min., while that in Kobe, where the shock was insensible, was 12 min.

Area of disturbance. As shown in Fig. 1 (Pl. IV), the earthquake was sensible within a land area about 75 km in length and 300 km in width. The area of moderate motion was nearly circular, with a mean diameter of about 320 km. Again, the area of strong motion is a small ellipse in the NW-SE direction, whose major and minor axes are respectively about 130 and 85 km. in length. It may be remarked that the south-eastern half of this meizoseismal ellipse coincides with the alluvial plain of Musashi, where the motion is much intensified owing to the softness of the ground; the centre of the ellipse not necessarily corresponding to the real earthquake epicentre.

The position of the latter seems in fact to be much eccentric and near the north-western end of the major axis, as considered in the next §.

Duration of preliminary tremor and position of epicentre. The durations of the preliminary tremor observed instrumentally at Tokyo and 7 other stations were as given in the following table.

Name of Station.	Latitude.	Longitude.	Duration of the total preliminary tremor.	Calculated epicentral distance.
			sec.	km.
(i) Tokyo.	35°43′ N	139°46′ E	7.5	**92**
Mito.	36 23	140 28	10.0	110
Tsukuba.	36 13	140 06	10.0	110
(ii) *Mean* ……	……	……	10.0	**110**
Miyako.	39 38	141 59	50.0	400
Ishinomaki.	38 26	141 19	42.5	347
(iii) *Mean* ……	……	……	46.3	**374**
(iv) Nagano.	36 40	138 10	21.8	**197**
Kobe.	34 41	135 11	48.6	391
Osaka.	34 42	135 31	50.0	400
(v) *Mean* ……	……	……	49.3	**396**

The duration of the preliminary tremor has been determined in the usual way from the different seismograms, with the exception of those obtained in Tokyo. The phase in question for the latter place has been taken in regard to the vibrations of macroseismic nature.

The figures in the last column of the above table have been calculated by the formula, x km$=7.27\ y$ sec.$+38$, in which x and y are respectively the epicentral distance and the duration of the preliminary tremor. Drawing on the map (Fig. 1) five circles with radii equal to the calculated distances of (i) to (v) about the respective positions as centres, we see that four of these meet near one another in the southern part of the province of Kotsuke. The probable position of the epicentre, indicated in the figure by a small cross (×), is situated in the northern part of the province of Musashi, namely, at about latitude 36°¼ N, and longitude 139°¾ E, at a distance of about 55 km to the north-west of Tokyo.

Observation in Tokyo. Time of Occurrence = 2h 17m 35s A.M.

Initial slow displacement. The seismograms furnished by the long-period horizontal pendulum instruments in Tokyo, three of which are reproduced in Pl. VI, are interesting in showing apparently no preliminary tremor, but beginning at once with a large slow vibration of period of about 7.5 sec., followed by a number of the proper pendulum oscillations. The initial displacements in the EW and NS directions, meaned from the different diagrams, are as follows :—

Motion toward East = 3.3 mm.
" " North = 3.2 "
Resultant displacement = 4.6 mm ; Direction, N 46° E.

Thus it will be observed that the direction of the initial (slow) motion was in this case approximately perpendicular to the line joining Tokyo with the earthquake origin, the vibration probably belonging to the category of the transverse wave[*]. A circumstance, which gives support to this latter supposition, is that the horizontal pendulum diagrams obtained at the other stations, whose epicentral distances were greater than that of Tokyo, showed no distinct slow vibration at the commencement, the preliminary tremor being generally well marked, due possibly to the slower transit rate and the consequent retardation of the transverse wave. The total duration of the earthquake motion in Tokyo was 24 min.

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[*] See also an account of the earthquake of Jan. 21, 1906, which originated off the south-eastern coast of the Main Island. The *Bulletin*, Vol. I, p. 145.

The results of studies on the nature of the vibrations occurring at the commencement of an earthquake, observed near the origin of disturbance, will be published in the *Bulletin* from time to time, a general discussion on this subject being reserved for a future occasion.

Macroseismograph record obtained at Hitotsubashi (Tokyo). Fig. 2 (Pl. V) gives the preliminary tremor and the earlier and most active part of the principal portion of the earthquake motion as recorded by an ordinary Gray-Ewing-Milne type seismograph, which magnifies the EW, NS, and vertical components 3, 4, and 2 times respectively. It will be observed that in this macro-seismogram, which does not show the slow vibrations existing in the earthquake motion, the preliminary tremor is well defined, the principal portion beginning with conspicuous movements of large amplitude. In the following description of the seismogram, the complete period and the range of motion (double amplitude) are denoted by the symbols T and $2a$ respectively.

Horizontal Motion.

The motion was sensible for about 2 min.

Preliminary tremor. The movements were as follows :—

(NS) $T = 0.85$ sec., Max. $2a = 1.00$ mm.
(EW) $T = 0.82$ „ Max. $2a = 0.73$ „

Principal portion. The motion was about 3 times greater in the NS than in the EW component, this being contrary to what is usually the case with strong Tokyo earthquakes, in which the EW component greatly predominates. For the first 2.3 sec., the vibrations were comparatively small and principally in the NS component :—

(NS) $T = 1.04$ sec., Max. $2a = 9.5$ mm.
(EW) $T = 0.17$ „ Max. $2a = 1.3$ „ (ripples).

Then the motion became much larger, there being 4 displacements (marked, in Fig. 2, respectively *cd*, *de*, *ef*, and *fg*) composing 2 vibrations as follows :—

1st displacement....	11.3 mm toward N, 4.5 mm toward W; Resultant $2a = 12.3$ mm, toward N22°W.
2nd „	16.3 mm toward S, 5.3 mm toward E; Resultant $2a = 170$ mm, toward S18°E.
3rd (Max.) „	22.0 mm toward N, 7.7 mm toward W; Resultant $2a = 23.3$ mm, toward N19°W.
4th „	9.3 mm toward S, 7.3 mm toward E; Resultant $2a = 11.8$ mm, toward S38°E.

The above 4 displacements, together lasting 2.0 sec., constituted the most active part of the earthquake; the 2nd and 3rd displacements forming the maximum vibration of $2a =$ **23.3** mm, and period = **0.95** sec., whose maximum acceleration was 510 mm per sec. per sec. As the mean direction of motion was N24°W–S24°E, these movements took place approximately parallel to the line joining the earthquake origin with the observing place and are due probably to the longitudinal wave. The subsequent motion was smaller, but continued active for about 1m 12s, the period being as follows :—

$$\left.\begin{array}{ll}(\mathrm{NS}) & T = 0.79 \text{ sec.} \\ (\mathrm{EW}) & T = 0.81 \quad ,, \end{array}\right\} \text{average, } \mathbf{0.80} \text{ sec.}$$

Vertical Motion.

Preliminary tremor. The motion was very small.

Principal portion. The motion which was small during the first 3.5 sec., was active during the next 18 sec., and consisted of the following vibrations :—$T = 0.47$ sec., Max. $2a = 1.3$ mm.

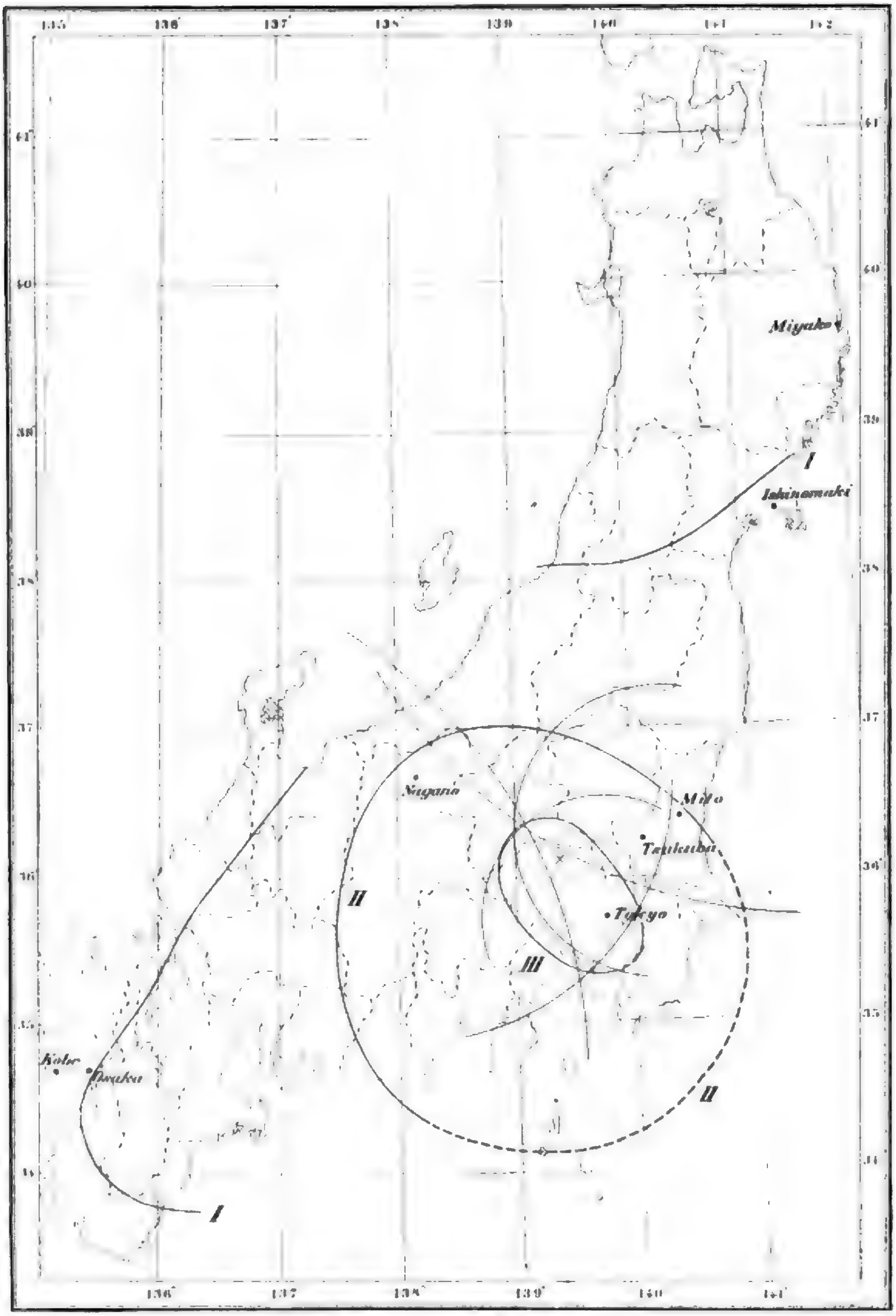
Observation at Hongo (Tokyo). The maximum macro-seismic motion at Hongo was $2a = 10.4$ mm, $T = 0.7$ sec., nearly in the NS direction.

Fig. 1. Tokyo Earthquake of Nov. 22, 1907.

I, II and III are respectively the boundaries of the areas of *slight*, *moderate*, and *strong* movements.

Arcs in red are drawn about the different places as centres with radii calculated from the duration of the preliminary tremor.

(×)......Probable Position of the Earthquake Origin.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Nagano
Mito
Tsukuba
Tokyo
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III
II
Kobe
Osaka
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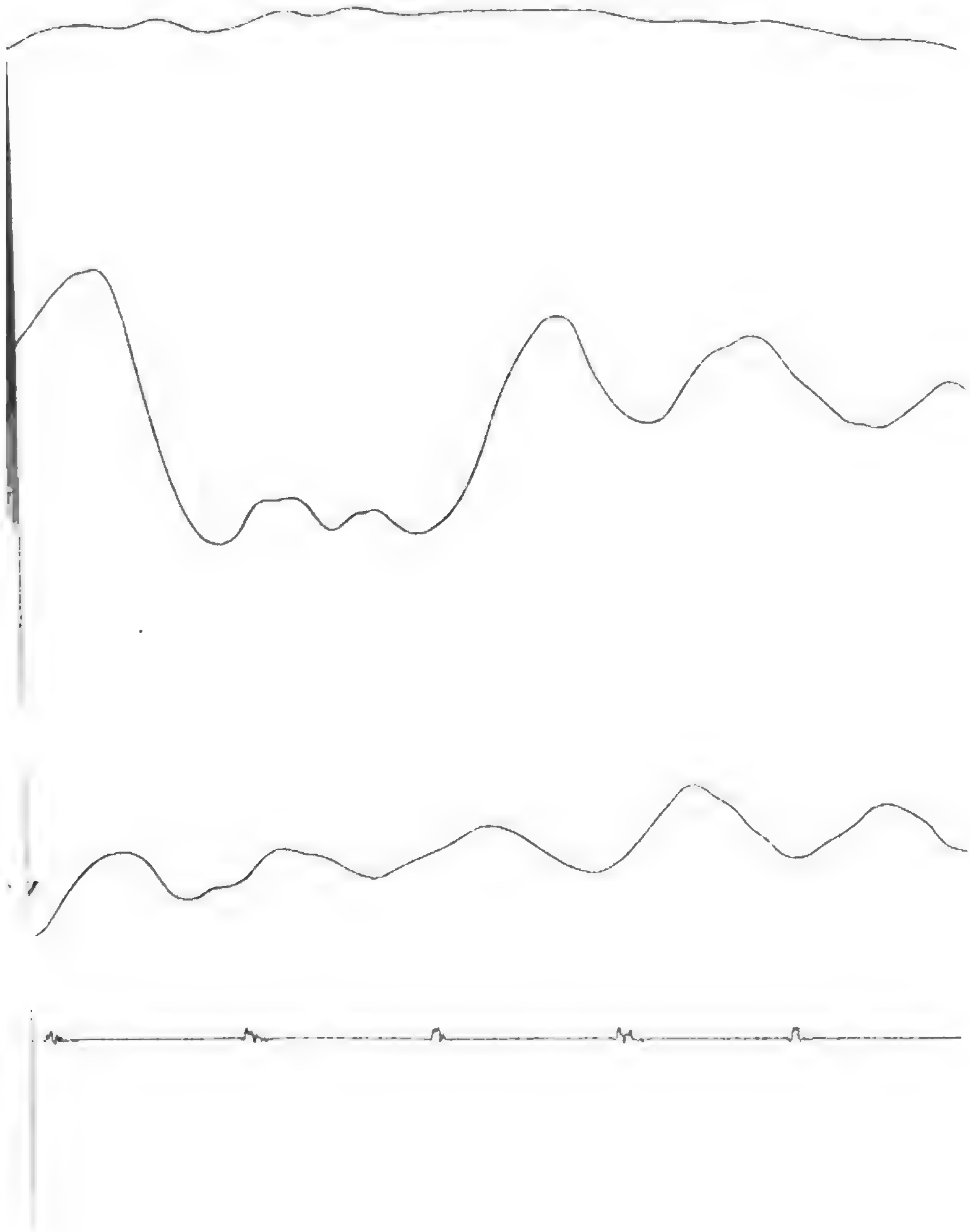
---- Boundary of provinces

egn:

PL. V.

gen: Vertical Component, 2 times.
NS „ 4 „
EW „ 3 „



Horizontal Pendulum Record obtained at Mito during a Storm.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. VII to IX.

Instances of remarkable inclination of the ground observed in Tokyo during a storm have been described in the *Publications*, No. 21, and the *Bulletin*, Vol. I, No. 4. The present note gives an account of a similar case of the tilting recorded on March 23, 1907, at the meteorological observatory of Mito ($\varphi=36°23'$ N; $\lambda=140°28'$ E), with the NS component Omori horizontal pendulum, whose recording cylinder made one revolution in 24 hours, and whose instrumental constants were as follows:—

Pendulum period, when suspended vertically $= T_0 = 1.74$ sec.

Period of Horizontal Pendulum actually set up $= T = 32$ sec.

Multiplication ratio of the pointer $= n = 20$.

Displacement* of the writing index corresponding to the tilting of 1″

$$= r = L \times n \times \sin 1'' \times \frac{T^2}{T_0^2} = 24.57 \text{ mm.}$$

Fig. 1. (Pl. VII) gives the tiltometer record in question between 10 a.m. and 5 p.m., on the 23rd.

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* In the "Bulletin," No. 4, *r* has by mistake been defined as the angle of tilting equivalent to 1 mm displacement of the writing index.

Storms on 22-24, March, 1907. From Fig. 2 (Pl. VIII)*, which shows the condition of the weather at 6 a.m. on March 23rd, 1907, it will be observed that there existed simultaneously two cyclones, (I) and (II), whose tracks were parallel to the general course of the Islands, and were over the Pacific Ocean and the Japan Sea respectively. The cyclone (I) appeared on the 21st off the south-eastern coast of Formosa, progressed toward north-east, and approached the south-eastern coast of the Main Island about the noon of the 23rd. The other cyclone, (II), which originated on the 20th at the Yantzse Valley, China, passed through the Tsushima Strait and approached on the 24th the western coast of Hokkaido. Both of these cyclones, which were at first shallow, rapidly increased in intensity with their eastward movement, the storm already extending over the whole of the Main Island on the afternoon of the 22nd. When the centre of the depression (I) approached on the 23rd the peninsula of Awa and Kazusa, the minimum barometric pressure of 744 mm was recorded at Choshi ($\varphi=35^\circ 44'$ N, $\lambda=140^\circ 55'$ E) at 1 p.m. The minimum pressure at Mito was 745.8 mm at 1 p.m. On the Japan Sea side, the minimum pressure, due to the cyclone (II), was 749.9 mm and was observed at Suttsu (province of Iburi, Hokkaido), at 9 p.m., on the 23rd.

Tilting of the ground. A marked southward inclination began to set in about 0h 30m p.m.; the displacement of the recording index of the instrument in that direction being 92 mm on record, which corresponds to a level inclination of 3.7″. This tilting was accomplished in the time interval of about 1h 50m, the extreme southward inclination having been reached at 2h 20m p.m. Thereafter the northward inclination began to set in.

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* The weather map is reproduced from the March (1907) number of the "Kisho Yoran," published by the Central Meteorological Observatory.

Thus it will be observed that the commencement of the sudden southward tilting was at about 30 min. before the epoch of the minimum barometric pressure at Choshi and Mito; the passage of the centre of cyclone producing, as in the case of the storm on Oct. 10th and 11th, 1904, not an elevation but the depression of the ground. This is probably due to the fact that the deep barometric cyclone was accompanied, or rather followed, by an increase of the height of sea water, to an amount greater than the equivalent of the barometric fall, as explained in the next §.

Mareogram at Choshi. Fig. 3 (Pl. IX) is a reproduction of the tide gauge diagram obtained on March 22nd and 23rd, 1907, at Choshi (province of Shimosa), which place is situated at the month of the River Tone, near Cape Inuboe, at a distance of about 80 km to the SES of Mito*. The disturbances of the water, consisting in the secondary undulations proper to the coast of observation began to become marked from about 4½ a.m. on the 23rd, continuing to increase till midnight of the same day. The level of the sea also began to rise, the greatest limit being reached at about 2 p.m. to a few minutes after 3 p.m., when the water thus abnormally accumulated was about 2½ *shaku* (=75.8 cm) higher than the level according to the usual tide movement, and 1.12 *shaku* (=34.0 cm) than the highest water during the preceding day. The time of the greatest water accumulation at Choshi thus nearly coincided with the moment of the maximum southward tilting at Mito. The difference of the highest mean level at about 3 p.m. (23rd) over that of the mean low water occurring about 3 hours earlier is some 1.45 *shaku* (=44 cm), which may be taken as the differential increase of the height of the sea level near the position of the cyclone over that in the neighbouring portions of the ocean. As the difference of the barometric pressure at the minimum centre and the coast near it was probably about 10 mm, or about 14 cm of water column, we see that the resultant relative pressure at the ocean bottom immediately after the passage of the cyclone centre is increased by an accumulation of water nearly 30 cm in height, extended over the sea surface of no insignificant dimension. This probably accounts for the tilting of the ground toward the centre of barometric depression, when the path of the latter is over the Pacific.

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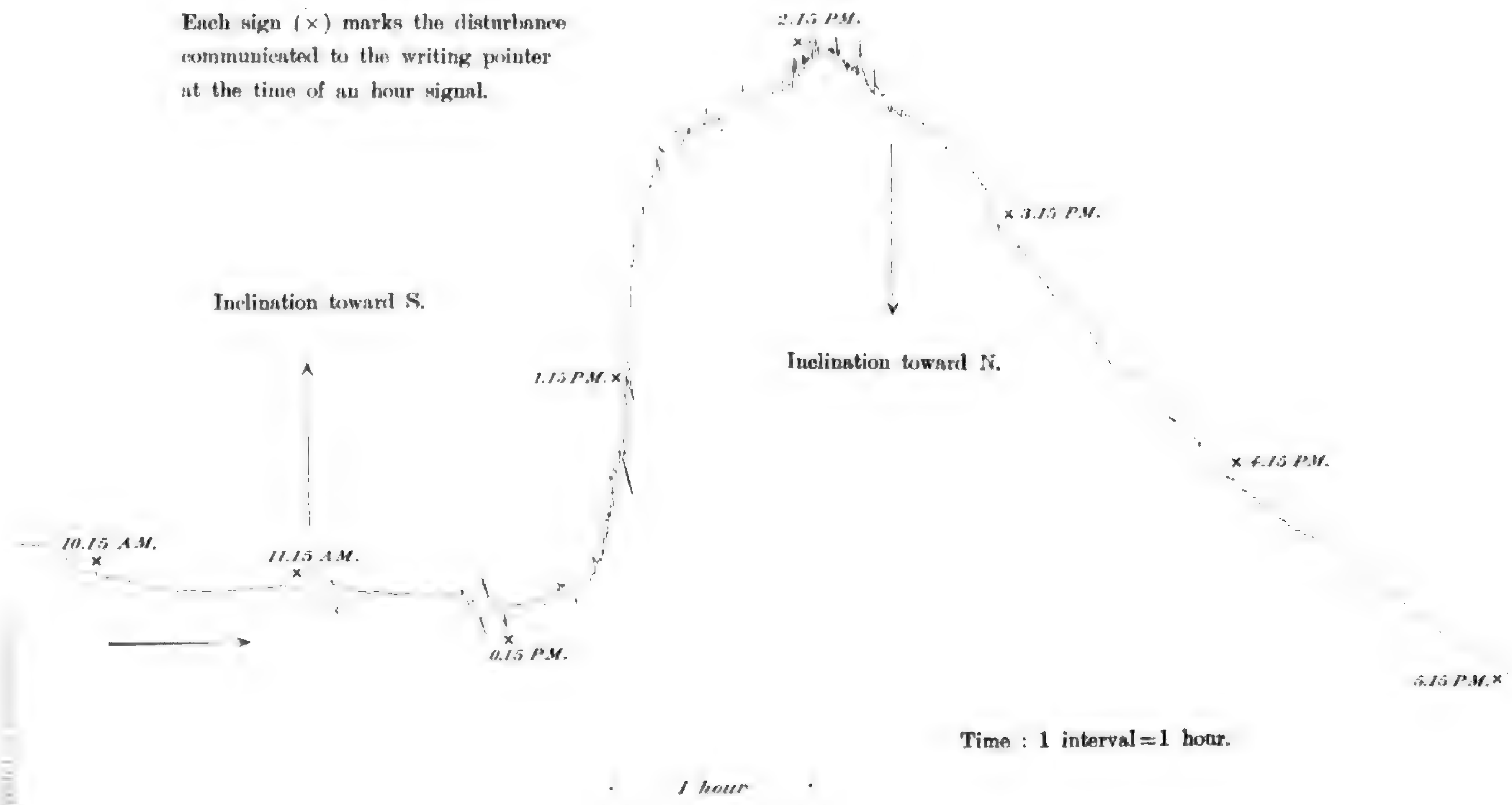
* For the copy of the mareogram I am indebted to Prof. Dr. T. Kondo of the Interior Department.

Fig. 1. Omori Horizontal Pendulum (Tiltometer) Diagram.
Mito, March 23, 1907. Pendulum Period = 32 sec.

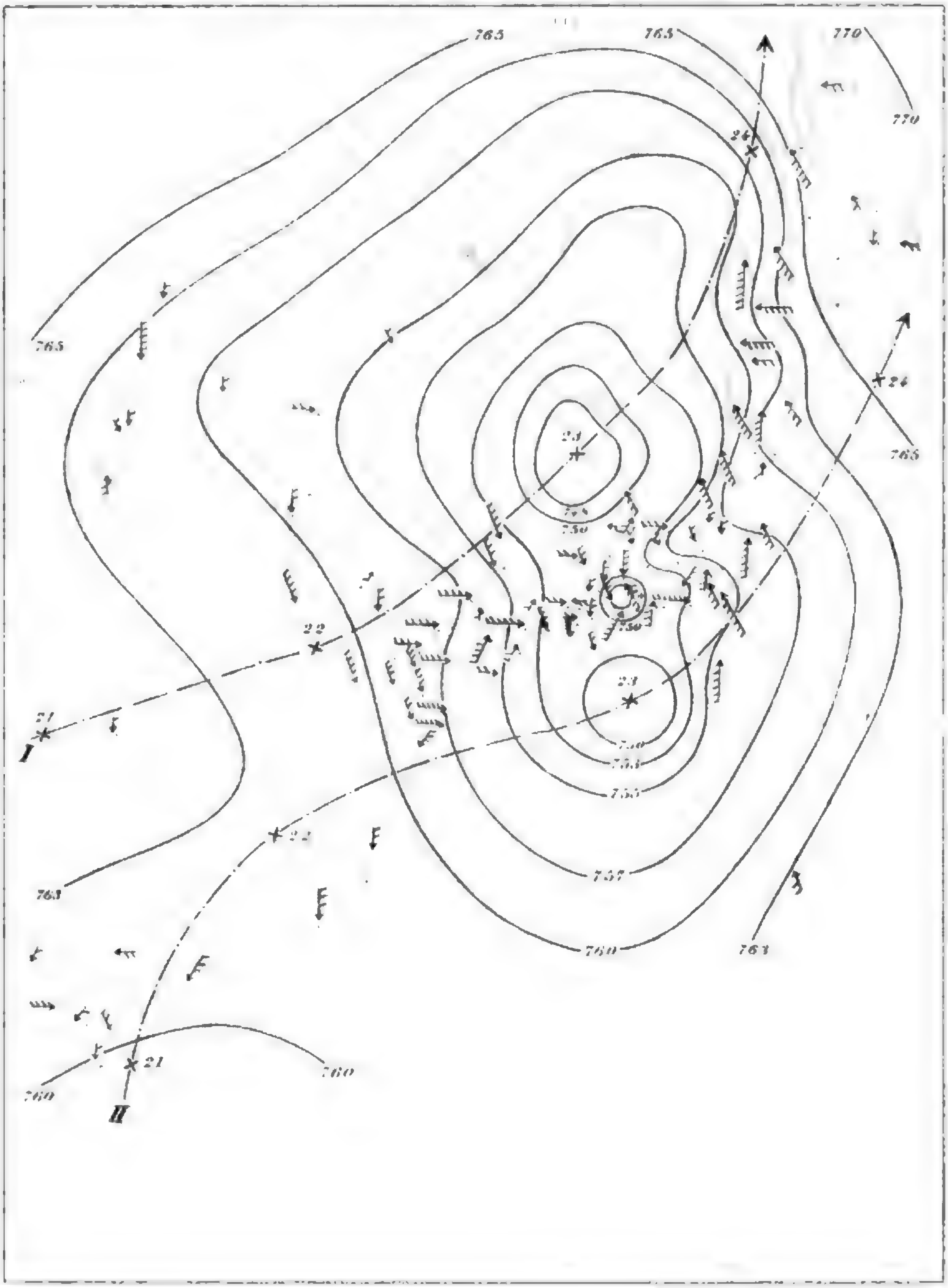


Each sign (×) marks the disturbance communicated to the writing pointer at the time of an hour signal.

Time : 1 interval = 1 hour.

Fig. 2. Weather Map. March 23, 1907; 6 A.M.

The dotted lines (I) and (II) give the paths of the two cyclone centres, whose positions at 6 A.M. of the successive days are each indicated by a small cross (×).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Note on the Annual Variation of Seismic Frequency in Tokyo and Kyoto.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pl. X.

Introductory. As pointed out in a discussion of the seismic activity for Japan, taken as a whole, the variation of the frequency of the ordinary small shocks, whose number is minimum in the months of June, July, August, and September, is just the reverse of that of the destructive disturbances, whose number is maximum in July and August*. Again, with respect to the recent Japan earthquakes of submarine origin, the annual variation of the small shocks is found to be approximately opposite to that of the stronger or larger ones ‡. Relations like these between small and large seismic disturbances are what is to be expected from the nature of an earthquake, which is virtually equivalent to the removal of a weak point in the earth's crust; the more frequent occurrence of small shocks tending to prevent any abnormal accumulation of the underground stress. The non-occurrence of these disturbances, or, an unusually low seismic frequency may, on the other hand, facilitate the occurrence of great or destructive seismic disturbances. The reversal of the maximum and minimum epochs in the annual variation of large and small seismic shocks is also strikingly shown in the cases of the earthquakes recorded in Tokyo and Kyoto.

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* F. Omori: "Note on the Earthquake Investigation Committee Catalogue of Japanese Earthquakes." Jour. Sc. Coll., Imp. Tokyo Univ., Vol. XI, 1899.

‡ This number, Pl. XIX.

Seasonal variation of seismic frequency in Tokyo. The number of destructive and semi-destructive earthquakes, which shook Tokyo (Yedo) since the foundation of the city in 1590 by Tokugawa Iyeyasu, was 18, the first and last of which took place in 1615 and 1894 respectively. Of these, the maximum seasonal number of 7 occurred in Summer, while the minimum number of 3 occurred in Winter and Spring. On the contrary, the mean seasonal number of ordinary small earthquakes, observed instrumentally in Tokyo between 1876 and 1899, was minimum (=19.1 and 18.3) in Summer and Autumn, and maximum (=25.5) in Spring*, as shown in the following table.

Seasonal Seismic Frequency in Tokyo.

Season.	Mean seasonal number of ordinary eqkes. (1876–1899).	Number of destructive and semi-destructive eqkes. (1615–1894).
Spring (March, April, May).	25.5	3
Summer (June, July, August).	19.1	7
Autumn (Sept., Oct., Nov.)	18.3	5
Winter (Dec., Jan., Feb.)	23.9	3

As is graphically shown in Figs. 1 and 2 (Pl. X), the annual variation of the small earthquakes is almost symmetrically opposite to that of the destructive and semi-destructive shocks.

Annual variation of seismic frequency in Kyoto. Of the seismic disturbances recorded in Kyoto between 797, the year of its foundation, and 1867, when it ceased to be the Imperial capital, 1088 earthquakes were small shocks, and 32 were destructive or semi-destructive in or about the city*. The distribution in the 12 months of the year of these two classes of Kyoto earthquakes are as follows.

---

* See the *Publications*, No. 8.

Monthly Seismic Frequency in Kyoto. (797–1867).

Month.	Ordinary small eqkes. (1088 shocks.)	Destructive and semi-destructive eqkes. (32 shocks.)
January.	79	3
February.	82	0
March.	110	0
April.	102	0
May.	95	3
June.	91	4
July.	87	5
August.	95	7
September.	74	3
October.	87	2
November.	95	1
December.	91	4

Thus the small earthquakes indicate the maximum monthly number of 110 in March, and the minimum of 74 in September; while the larger ones show the minimum number of zero in February to April, and the maximum number of 7 in August. As will also be seen from the graphical illustrations in Figs. 3 and 4 (Pl. X), the annual variations of the two sets of earthquakes are nearly opposite to one another.

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* These numbers are revised results and differ slightly from those given in Jour. Sc. Coll., Imp. Tokyo Univ., Vol. XI.

Concluding remark. From the foregoing §§, it is evident that we must treat small and large earthquakes separately, in the discussion of seismic frequency with respect to the atmospheric pressure, the position of the moon, etc.

Annual Variation of Tokyo Eqke Frequency.

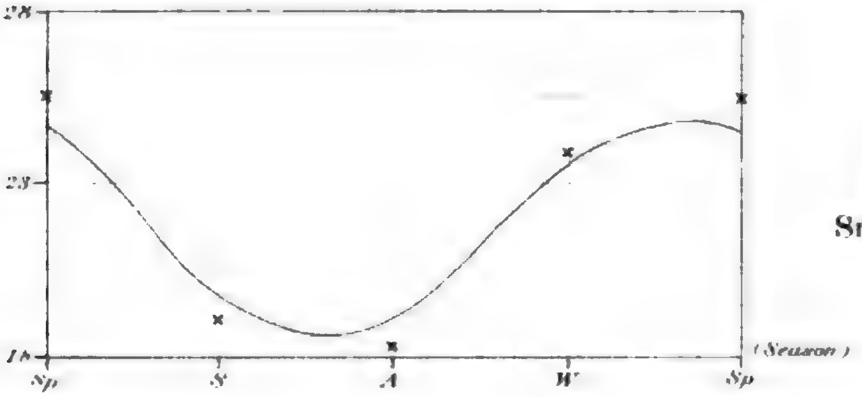

Fig. 1.
Small Eqkes.

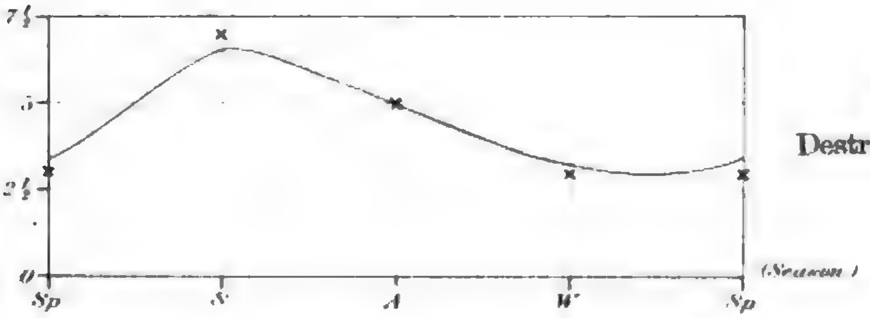

Fig. 2.
Destructive Eqkes.

Annual Variation of Kyoto Eqke Frequency.

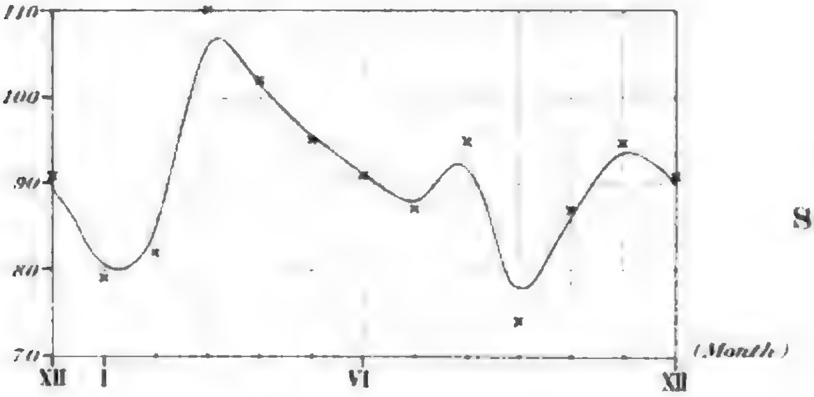

Fig. 3.
Small Eqkes.

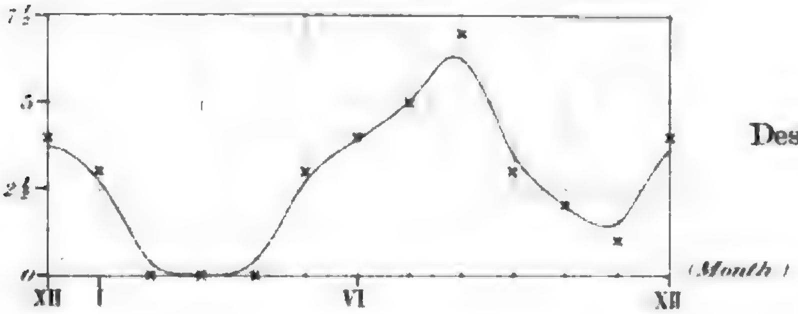

Fig. 4.
Destructive Eqkes.

List of Recent Volcanic Eruptions in Japan*.

By

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Member of the Imperial Earthquake Investigation Committee.

With Pls. XI-XIII.

Larger volcanic outbursts in recent years. Among the recent volcanic explosions in Japan, the most notable were the following five:—

(i) Explosion of Bandai-san. July 15, 1888; 7h 45m a.m.
(ii) " Azuma-san (Issaikyo-san). May 19, 1893; 11h 30m a.m.
(iii) " Adatara-san (Numashiri-yama). July 17, 1900; 6h 30m p.m.
(iv) " Tori-shima. August, probably between the night of 7th and that of 9th, 1902.
(v) Submarine eruption near the Minami Iwo-jima (South Sulpher Island). About the 5th of December, 1904.

Of these, the first four consisted each of a sudden steam explosion, the most violent being that of the Bandai-san, one of whose peaks was entirely destroyed. The three explosions of the Azuma-san, Adatara-san, and Tori-shima were much smaller, that of the first named mountain being probably the least. A rough idea of the comparative strengths of the explosions may be obtained from the masses blown off on the different occasions[6], which were approximately in the ratios of 3400 : 1 : 7 : 56, as follows :—

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* Translation, with additions, of the present author's paper in the Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 49, 1904.

	(volume of newly formed crater.)	
Bandai-san	1,700,000,000	cubic metres.
Azuma-san............	500,000	„
Adatara-san	3,600,000	„
Tori-shima............	28,000,000	„

Each of these four volcanic explosions caused a considerable damage, attended by loss of human lives, which was specially striking in the case of the Tori-shima, the total population of the island, about 125 in number, having been entirely wiped away without leaving even a trace.

The explosion of the Adatara-san was central, that is to say, took place from the filled up crater of the original volcano, while those of the Bandai-san, Azuma-san, and Tori-shima, were each an eccentric outburst, having occurred not in the original central crater.

The submarine volcanic outburst, (v), which took place near the Minami Iwo-jima, was very remarkable and consisted in the eruption of molten lava, resulting in the formation of a new island, about 145 metres in height and nearly 5 km in circumference. This island, made up of the loose material, again entirely disappeared about 1 year later.

Of the 5 cases of larger volcanic outbursts mentioned above, the first three occurred in the province of Iwashiro, in the northern part of the Main Island, while the two last occurred in the Pacific and belonged to the Fuji volcanic chain.

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[6] The estimation of the volume of newly opened crater of the Bandai-san was made by the late Professors S. Sekiya and Y. Kikuchi. Those relating to the three other volcanoes are based on the observations of the present author.

List of volcanic outbursts, 1893-1907. During the 14 years between 1893 and 1907, there were in Japan (Kuriles, Lyu-Kyu, and Formosa excepted) over 70 cases of volcanic outbursts, which consisted mostly in the explosions of steam; the mountains most active during this period being the following four:—

Asama-yama (province of Shinano)	about	31 times
Kirishima-yama (province of Hyuga)	,,	19 ,,
Aso-san (province of Higo)	,,	6 ,,
Shirane-san (province of Kotsuke)	,,	5 ,,

Besides these, Azuma-san (Issaikyo-san), Adatara-san (Numashiri-yama), Tarumae-san (in Hokkaido), Komaga-take (Do.), Katta-dake (province of Rikuzen), and others were also more or less active; there being also two cases of submarine eruptions off the Pacific coast. The approximate positions of these volcanoes, 14 in number, are as follows.

Volcano.	Latitude (N)	Longitude (E)
Komaga-take.	42° 04′	140° 41′
Tarumae-san.	42 42	141 23
Katta-dake.	38 08	140 27
Azuma-san.	37 44	140 15
Adatara-san.	37 38	140 16
Bandai-san.	37 37	140 04
Shirane-san.	36 38	138 33
Asama-yama.	36 25	138 30
Iwo-dake.	36 15	137 36
Aso-san.	32 54	131 05
Kirishima-yama.	31 56	130 52

Volcano	Latitude (N)	Longitude (E)
Near Bayonnise Rock.	31° 55′	139° 54′
Tori-shima.	30 27	140 07
Eruption near Minami-Iwo-shima.	24 13	141 29

As a strong volcanic eruption has usually a number of smaller followers, it is often difficult to count the exact number of the outbursts. These small secondary ones have, in so far as they can be identified as such, been excluded from the following list of the volcanic disturbances.

Table I. List of Volcanic Outbursts in Japan, 1893–1907.

Volcano.	Date.	Time of Outburst.	REMARKS.
	1894		
Kirishima-yama.	Feb. 25	10^h 30^m A.M.	Detonations. Ashes thrown out.
„	„ 28	8 20 „	Loud detonations.
Aso-san.	March 7	5 - - „	Detonations. Ashes thrown out.
	Rumbling sounds also heard at 7.13; 8.46; 9.15; 9.23; 9.40; 10.02 and 10.25 A.M. of the same day, the last being the strongest.		
„	„ 13	10 40 A.M.	Detonations and explosion.
Azuma-san (Issaikyo-san).	„ 16		Detonations. Ashes thrown out.
„	April 4	Noon.	„ „
Asama-yama.	„ 6	1 — A.M.	„ „
„	„ 11	9 — P.M.	Loud detonations. Ashes thrown out.
Azuma-san.	„ 12	10 — A.M.	Ashes thrown out.
Asama-yama.	„ 17	8 — A.M.	Detonations. Ashes thrown out.
„	„ 28	6 20 P.M.	Outburst.
„	„ 30	0 — A.M.	Loud Detonations. Ashes thrown out

Volcano.	Date.	Time of Outburst.	REMARKS.
Aso-san.	May 24	Midnight.	Detonations. Ashes thrown out.
Asama-yama.	June 14	9^h 30^m A.M.	Loud detonations. Ashes thrown out in large quantity.
Aso-san.	,, 23	8 — P.M.	Loud detonations. Ashes thrown out.
Tarumae-san.	Aug. 17	6 — P.M.	Smoke emitted.
Aso-san.	,, 30	5 — A.M.	Detonations.
	1895		
Katta-dake.	Feb. 15	9 — A.M.	Smoke emitted.
,,	,, 19	8 30 A.M.	,,
Azuma-san (Issaikyo-san).	March 8	7 32 A.M.	Detonations and emission of smoke.
,,	,, ,,	9 40 P.M.	,, ,,
Kirishima-yama.	July 16	0 30 P.M.	,, ,,
Kumaga-take (Katta-dake).	Sept. 27	5 — A.M.	,, ,,
Kirishima-yama.	Oct. 16	0 30 P.M.	,, ,,
,,	Dec. 18	3 45 P.M.	Loud detonations and emission of smoke.
	1896		
Kirishima-yama.	March 15	8 26 A.M.	Explosion, accompanied by emission of smoke and falling of ashes.
,,	June 26	1 — A.M.	Detonations and emission of smoke. Ashes thrown out.
,,	Dec. 21	1 15 P.M.	Explosion. Ashes thrown out.
	1897		
Zo-O-san (Katta-dake)	Jan. 11	0 30 A.M.	Detonations. Smoke emitted.
Aso-san.	End of Feb. to the beginning of March.	——	Detonations continued for several days, being strongest on March 3.
Shirane-san.	July 31	5 — A.M.	Detonations and emission of smoke.
Kirishima-yama.	Sept. 4	8 — A.M.	Explosion.

Volcano.	Date.		Time of Outburst.	Remarks.
	1898			
Kirishima-yama.	Feb.	8	1^h —^{m} A.M.	Detonations and emission of smoke.
"	March	11	7 — P.M.	Loud detonations and explosion.
"	Dec.	30	11 — P.M.	" " "
	1899			
Asama-yama.	March	10	1 — P.M.	Detonations and explosion.
"	July	10	Night	Explosions, continuing for several days.
"	"	15	11 — A.M.	Loud detonations and explosion.
Kirishima-yama.	"	28	1 30 A.M.	" " "
Asama-yama.	Aug.	7	7 — P.M.	" " " Ashes fell for several days.
Adatara-san.	"	24	11 30 P.M.	Explosion.
Kirishima-yama.	Sept.	12	Morning	Detonations and explosion.
"	Oct.	13	3 05 A.M.	" "
"	Nov.	7	Morning	" "
Adatara-san.	"	12	7 30 P.M.	Explosion.
	1900			
Adatara-san.	Jan.	22	7 — A.M.	Detonations and explosion.
"	Feb.	7	6 — P.M.	" "
Kirishima-yama.	"	16	9 — A.M.	" "
Asama-yama.	"	19	5 — P.M.	Loud detonations and explosion.
"	March	1	From morning to noon.	" " "
"	"	22	Midnight	Detonations, followed by several others.
"	"	31	3 10 P.M.	Loud detonations and explosion.
Adatara-san.	July	17	6 30 P.M.	Great explosion. (See the 1st §)
Asama-yama.	"	21	—	Explosion.
Shirane-san.	Oct.	1	3 — A.M.	Feable detonations and explosion.
Asama-yama.	Nov.	19	4 30 P.M.	Explosion.

Volcano.	Date.	Time of Outburst.	Remarks.
Asama-yama.	Dec. 14	4^h —^{m} A.M.	Feeble shaking and explosion.
	1901		
Asama-yama.	April 20	0 25–5 00 P.M.	Explosion
"	" 21	10 30 A.M.	Emission of smoke.
"	May 25	10 50 A.M.	" "
"	" 26	2 00 P.M.	" "
"	July 21	Evening	Explosions continued for several days.
"	Aug. 6–8		" " (Ashes fell also on 9th and 10th.)
	1902		
Asama-yama.	Aug. 5	1 — P.M.	Detonations. Ashes thrown out.
Tori-shima.	Aug. (probably between evening of 7th and that of 9th)		Great explosion. (See the 1st §)
Shirane-san.	Sept. 5	Evening	Small explosion.
"	" 17	1 — P.M.	" "
	1903		
Kirishima-yama.	Aug. 29	2 30 P.M.	Detonations and explosion.
"	Nov. 25	9 — A.M.	Great detonations and explosion.
	1904		
Asama-yama.	Aug. 4	Noon	Smoke emitted, and ashes thrown out.
Near the Minami Iwo-jima.	(About Nov. 28)	—	A great submarine eruption, resulting in the formation of a new island.
	1905		
Komaga-take.	Aug. 20	11 — P.M.	Explosion. Ashes continued to be thrown out till the end of the year.
Shirane-san.	Oct. 24(?)	—	Smoke emitted, and ashes thrown out.
	1906		
Asama-yama.	April 6	Early morning	Smoke emitted.
In the vicinity of Bayonnaise Rock, to the SE of Aogashima.	April (probably between 7 and 13)	—	A submarine eruption, which continued probably for about one week. A great quantity of pumice was found floating on the sea surface.

Volcano.	Date.	Time of Outburst.	REMARKS.
Aso-san.	June 8	5ʰ — P.M.	Detonations, followed by an explosion. A new crater, about 50 ft in length and 24 ft in width was formed.
	1907		
Asama-yama.	Jan. 18	Continued from the evening of 18th to the morning of 19th	Smoke emitted.
,,	March 28	6 — A.M.	Smoke emitted, and ashes thrown out.
,,	Aug. 24	Early morning	,, ,,
Iwo-dake. (in Shinano)	Dec. 11	——	Explosion. Ashes were thrown out.

Annual variation of the frequency of the volcanic outbursts. The distribution in the 12 months of the year of the 80 cases of volcanic disturbances contained in the list given in the preceding § is shown in the 2nd column of the following table; the figures in the 3rd column, taken from the late Mr. Ogashima's work, "Nippon Saiishi," (*A compendium of unusual events in Japan*), being the annual distribution of the 113 volcanic outbursts, which happened in Japan since the earliest historical times down to 1885*.

Table II. Volcanic Eruptions in Japan.

Month.	80 Vol. Outbrusts in recent years. 1893-1907	113 Vol. Outbursts recorded in history. 685-1886	*Sum.* (193 Outbursts).
I	3	6	**9**
II	9	20	**29**
III	12	13	**25**

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* For accounts of historical volcanic outbursts in Japan, the reader is also referred to Prof. John Milne's paper, "the volcanoes of Japan," in the Trans. Seism. Soc. Japan, Vol. IX.

Month.	80 Vol. Outbursts in recent years. 1893-1907	113 Vol. Outbursts recorded in history. 685-1886	*Sum.* (193 Outbursts).
IV	11	14	**25**
V	3	8	**11**
VI	4	4	**8**
VII	8	7	**15**
VIII	11	14	**25**
IX	5	9	**14**
X	4	3	**7**
XI	5	9	**14**
XII	5	6	**11**

The annual variations of the recent volcanic outbursts and of those which occurred in the historical times are, as illustrated in Figs. 1 and 2 (Pl. XI), mutually alike, each showing two distinct maxima of the frequency. The monthly distribution of the two sets of eruptions taken together is given in the last column of the above table and illustrated in Fig. 3. From the latter it will be seen that the absolutely greatest frequency (29) of eruptions occurred in February; the three months of February, March, and April together forming the 1st, or principal epoch of volcanic activity, followed by the principal minimum in June. The 2nd, or smaller, maximum frequency (25) occurred in August.

Comparison with the annual variation of seismic frequency. To compare the annual variation of the frequency of the volcanic eruptions with that of the seismic frequency, I give, in Table III, the mean monthly percentage numbers of earthquakes observed instrumentally at the meteorological observatories of

Nagoya, Gifu, and Kumamoto, which places are shaken mostly by seismic disturbances of inland origin; the figures having been deduced from the data given in the "Publications of the Imp. Earthquake Inv. Comm.", No. 8.

Table III. Mean Monthly Percentage Numbers of Earthquakes at Nagoya, Gifu, and Kumamoto.

Month.	Nagoya.	Gifu.	Kumamoto.	*Average.*
I	13.3	10.7	10.9	**11.6**
II	7.5	8.2	9.3	**8.3**
III	13.0	9.9	9.9	**10.9**
IV	9.6	13.9	9.5	**11.0**
V	9.0	9.2	10.5	**9.6**
VI	6.3	6.9	9.6	**7.6**
VII	6.0	6.0	4.9	**5.6**
VIII	11.2	5.5	7.5	**8.1**
IX	6.6	6.5	7.5	**6.9**
X	6.9	8.2	8.8	**8.0**
XI	4.8	8.6	6.1	**6.5**
XII	5.8	6.5	5.5	**5.9**

According to the average values of the monthly seismic frequency, which are given in the last column of Table III, and which are graphically illustrated in Fig. 4, the annual variation of the frequency of the earthquakes of inland origin shows the epoch of the principal maximum (=11) in March and April, with the principal minimum (=5.6) in July; there being an epoch of a secondary maximum (=8) in the months of August to October. The variation in question may thus be regarded as being on the whole approximately similar to that of the frequency of the volcanic eruptions.

With respect to the cause of the frequency variations of these two phenomena, it is to be remarked that the earthquakes of inland origin are much affected by the atmospheric pressure, as discussed in the *Publications*, No. 8; the 1st, or principal, seismic maximum above mentioned being due probably to the barometric maximum in the annual variation. The 2nd, or smaller, seismic maximum may possibly be due to the more extensive or stronger among the earthquakes of inland origin taken into consideration; the annual variation of large and small shocks being in general opposite to one another. The cause for the two maxima in the frequency variation of the volcanic eruptions is probably the same as in the case of those of the earthquakes. It is needless to add that further and more strict investigations in these connections are necessary, especially for the explanation of the secondary maximum in the frequency of volcanic eruptions[*].

Seasonal numbers of volcanic eruptions. The following table gives the distribution in the four seasons of the year of the 193 volcanic eruptions (Table II) and of the percentage numbers of the earthquakes observed at Nagoya, Gifu, and Kumamoto based on the data given in Table III.

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[*] In the Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 56, I have stated the view that the secondary maximum in the frequency of the volcanic eruptions may be due to the pressure of the sea water at the bottom. The supposition stated in the present paragraph seems to be the more likely one.

Table IV. Seasonal Distribution of the Volcanic Eruptions and the Percentage Numbers of the Earthquakes.

Season.	Volcanic Eruptions. (193)	Seismic Frequency.			
		Nagoya.	Gifu.	Kumamoto.	*Mean.*
Spring (March, April, May.)	61	31.6	33.0	30.3	31.6
Summer (June, July, August.)	48	23.5	18.4	22.3	21.4
Autumn (Sept., Oct., Nov.)	35	18.4	23.2	22.7	21.4
Winter (Dec., Jan., Feb.)	49	26.5	25.4	24.7	25.5

Thus, for the volcanic eruptions, the greatest seasonal number of 61 occurred in Spring, being 1.7 times greater than the least number, which occurred in Autumn. For the mean frequency of the earthquakes, the greatest percentage number of 31.6 occurred also in Spring, being about 1.5 times greater than the least number of 21.4, which occurred in Summer and Autumn. The curves graphically representing the variations of the seasonal frequencies of the eruptions and the earthquakes, given in Figs. 5 and 6, (Pl. XII), will be seen to be on the whole similar to one another.

Numbers of volcanic eruptions in the successive years. Table V gives the number of the volcanic eruptions for each of the years 1894 to 1907, and for the sake of comparison, the total numbers of earthquakes (exclusive of teleseismic disturbances) observed in Japan during the successive years.

Table V. Yearly Numbers of Volcanic Eruptions and Earthquakes in Japan. 1894–1907.

Year.	Number of Volcanic Eruptions.	Number of Earthquakes*.
1894	17	2,729
1895	8	1,417
1896	3	1,906
1897	4	1,727
1898	3	1,561
1899	10	1,682
1900	12	1,831
1901	6	1,615
1902	4	1,401
1903	2	1,242
1904	2	1,142
1905	2	1,901
1906	3	1,551
1907	4	1,642

(* Formosa excluded)

From Figs. 7 and 8 (Pl. XIII), which graphically illustrate the results contained in Table V, it will be seen that the relations to time of the numbers of the eruptions and the earthquakes are rather alike to each other; in each case the absolutely greatest number occurring in 1894, and a maximum in 1900.

From what has been said in the foregoing §§, the volcanic activity in Japan seems to follow approximately that of earthquakes. This is in accordance with the fact that large volcanic eruptions and destructive earthquakes often take place in nearly the same epoch in different parts of a great seismic zone.

Annual Variation of the Volcanic Eruptions and Earthquakes in Japan.

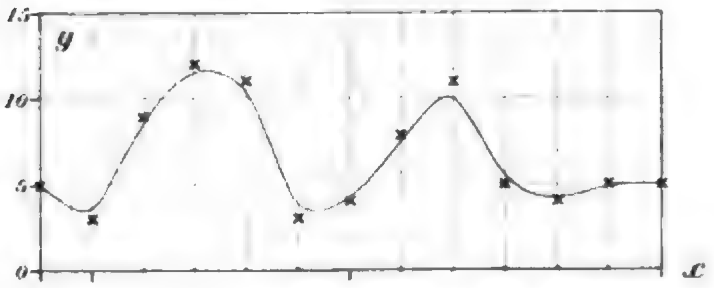


Fig. 1. 80 recent Volcanic Eruptions.

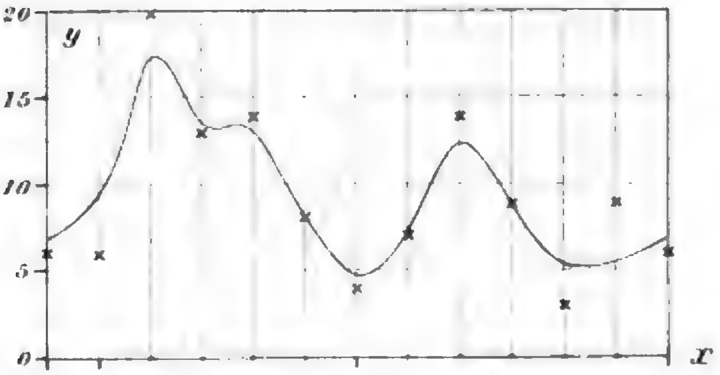


Fig. 2. 113 historical Volcanic Eruptions.

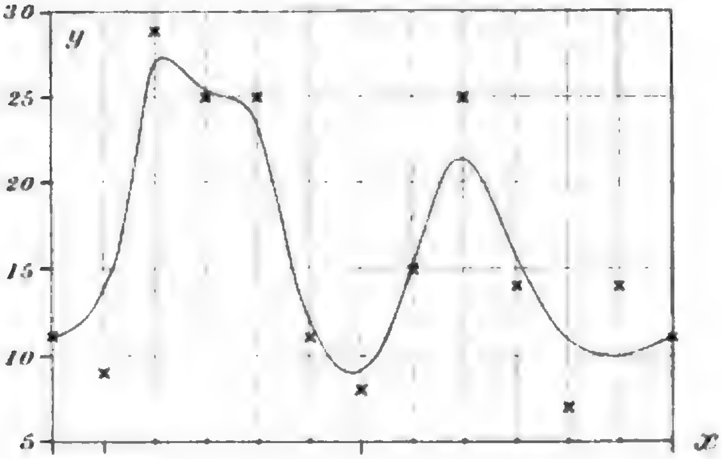


Fig. 3. 193 recent and historical Volcanic Eruptions.

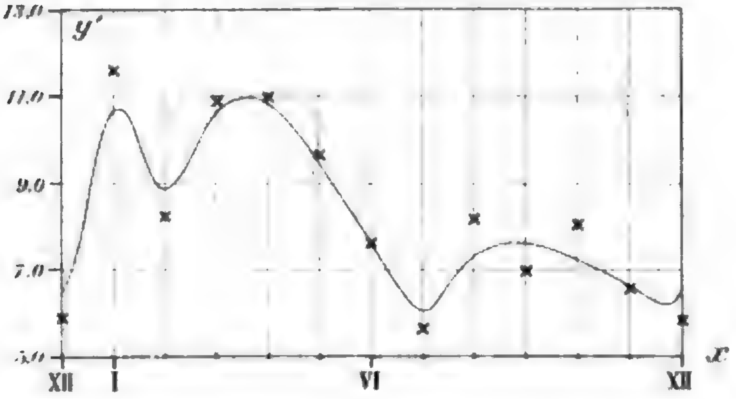


Fig. 4. Earthquakes of Inland Origin.

x = Time, in months.
y = Monthly number of volcanic eruptions in Japan.
y' = Mean monthly percentage number of earthquakes of inland origin.

Seasonal Distributions of the Volcanic Eruptions and Earthquakes in Japan.

Fig. 5. 193 Volcanic Eruptions.

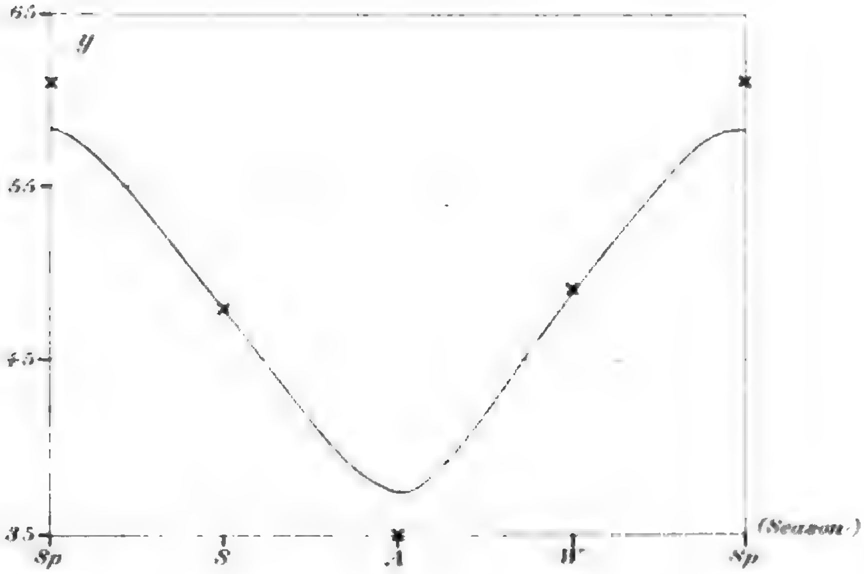
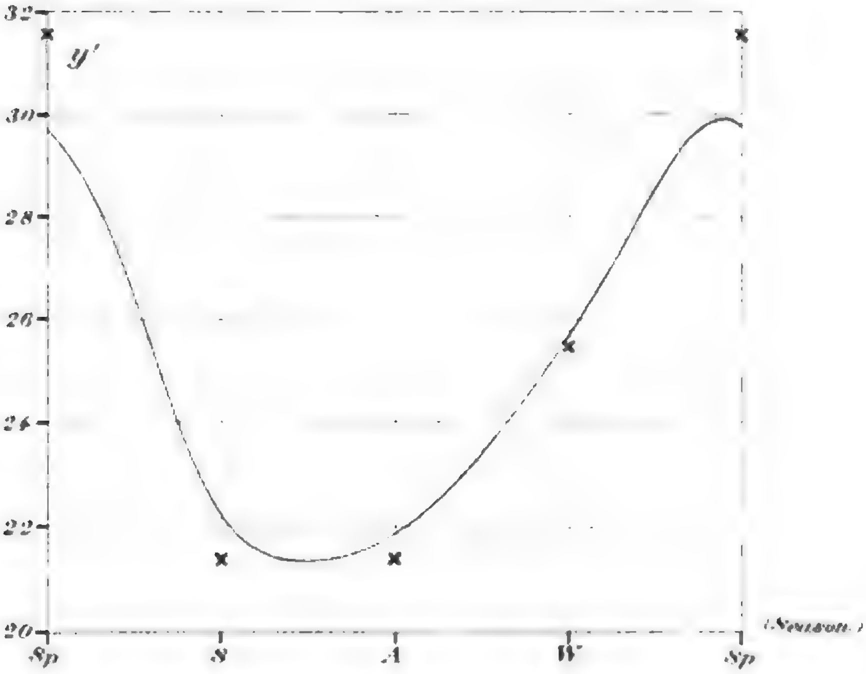


Fig. 6. Earthquakes of Inland Origin.



y = Monthly number of volcanic eruptions in Japan.
y' = Mean monthly percentage number of earthquakes of inland origin.

Variations of the Yearly Numbers of the Volcanic Eruptions and Earthquakes in Japan.

Fig. 7. Volcanic Eruptions.

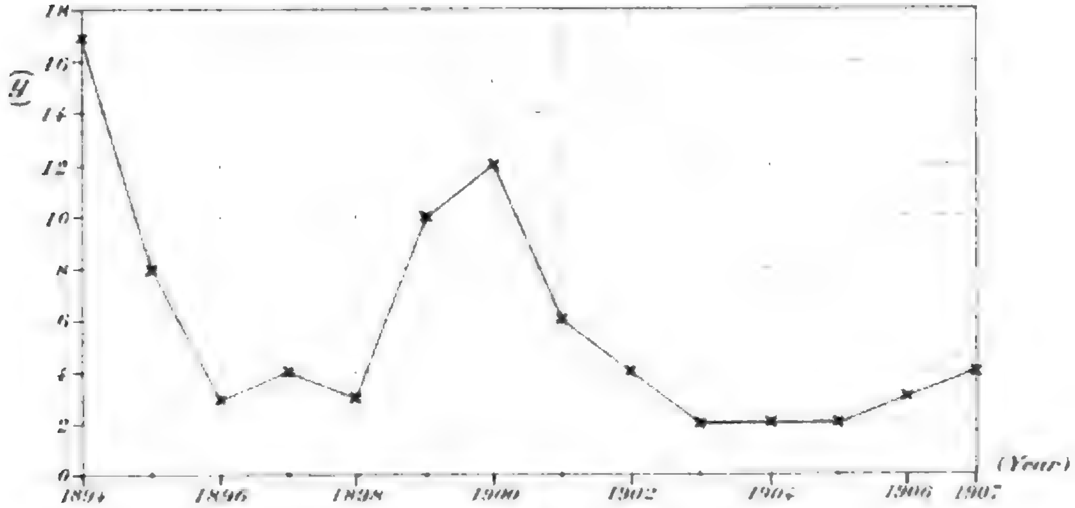
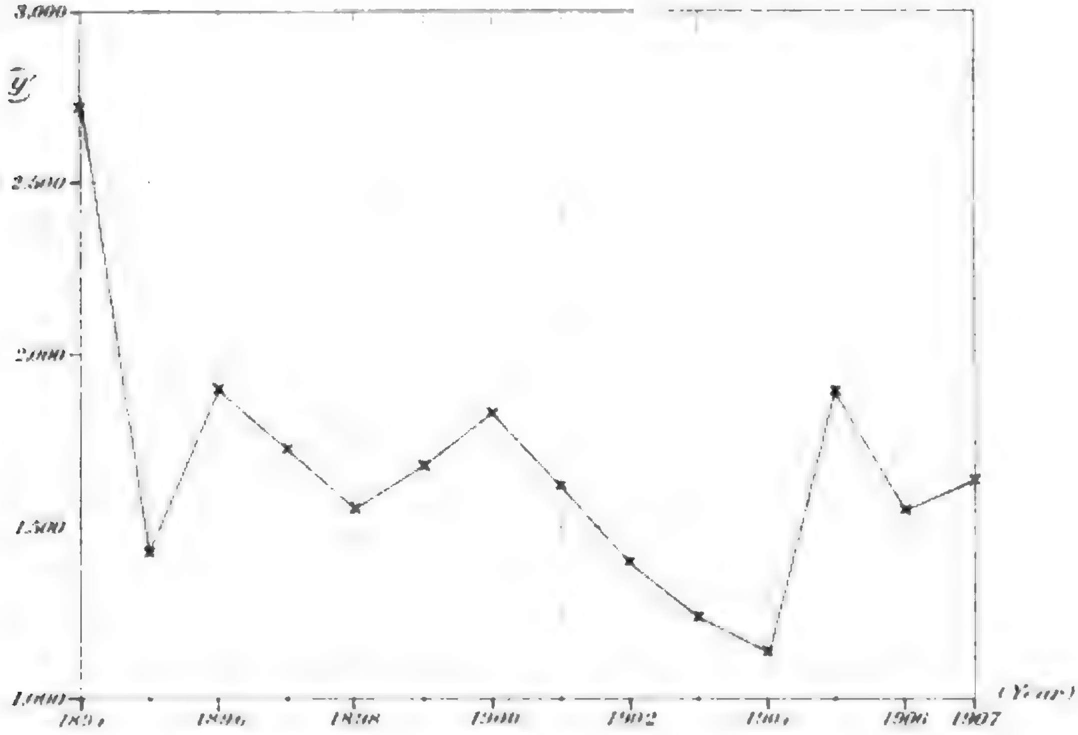


Fig. 8. Earthquakes.



y = Yearly number of volcanic eruptions in Japan.
y' = „ „ „ earthquakes in Japan (Formosa excepted).

On the Annual Variation of the Height of Sea-Level along Japanese Coasts. *2nd Paper.*

By

F. Omori, Sc. D.,

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With Pls. XIV-XIX.

Introductory. In a previous note* I have considered the relation to the barometric pressure and the seismic frequency of the annual variation during 1902 of the height of sea-level at Ayukawa and Misaki, which are situated on the Pacific coast of the Main Island. The present paper treats of the same relation for these two places during the year 1903, and also gives the discussion of the sea-level observations during 1904 made at Choshi (province of Shimosa) on the Pacific side, and at the four Japan-Sea coast stations of Otaru, Iwasaki, Wajima and Hamada. The data relating to the mean monthly heights of sea level at Choshi are based on the report of the meteorological observatory at that town, while those relating to all the other places have been furnished by the Survey Department of the General Staff of the Imperial Army; the tidal measurement at each place being made by means of an automatically recording mareograph. The approximate positions of the different stations, which are shown in Fig. 1 (Pl XIV), are as follows.

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* The "Publications of the Earthquake Inv. Comm.", No. 18.

Stations.	Latitude (N).		Longitude (E).	
Otaru.	43°	13′	141°	01′
Iwasaki.	40	36	139	55
Ayukawa.	38	18	141	31
Chōshi	35	44	140	50
Misaki.	35	10	139	37
Wajima (Wajima-zaki).	37	25	136	54
Hamada (Sotonoura).	34	55	132	05

Height of sea-level at Ayukawa and Misaki, in 1903. Table I gives the mean relative monthly heights of sea surface for 1903 at Ayukawa (province of Rikuzen) and Misaki (province of Sagami), while Table II gives the mean monthly atmospheric pressure for the same year deduced from the barometric observations at the meteorological observatories of Ishinomaki and Yokosuka, respectively near to the two mareograph stations above named.

Table I. Mean Monthly Relative Heights of Sea Level at ***Ayukawa*** and ***Misaki.*** **1903.**

Month.	Aynkawa.	Misaki.	*Mean.*
January.	131 mm	101 mm	116 mm
February.	75	60	68
March.	12	0	6
April.	0	19	10
May.	116	102	109
June.	187	185	186

Month.	Aynkawa.	Misaki.	*Mean.*
July.	257^{mm}	183^{mm}	220^{mm}
August	233	206	220
September.	246	190	218
October.	220	220	220
November.	166	191	179
December.	187	133	160

Table II*. Mean Monthly Barometric Heights at Ishinomaki and Yokosuka. **1903.**

Month.	Ishinomaki.	Yokosuka.	*Mean*
January.	$\overset{\mathrm{mm}}{700}+62.4^{\mathrm{mm}}$	$\overset{\mathrm{mm}}{700}+62.7^{\mathrm{mm}}$	$\overset{\mathrm{mm}}{700}+62.6^{\mathrm{mm}}$
February.	62.7	63.0	62.9
March.	64.2	63.9	64.1
April.	63.3	63.1	63.2
May.	60.0	60.1	60.1
June.	56.1	55.9	56.0
July.	56.5	57.1	56.8
August.	58.8	58.9	58.9
September.	61.2	60.6	60.9
October.	63.3	62.5	62.9
November.	63.4	63.1	63.3
December.	61.3	61.8	61.6

The 2nd and 3rd columns of Table III give the relative monthly values of the heights of sea surface and of the atmospheric pressure, respectively meaned from the Ayukawa and Misaki mareograph observations (Table I) and from the Ishinomaki and Yokosuka barometric readings (Table II), the figures indicated in the 4th column being the relative total amount of pressure expressed in height of water column at the sea bottom itself, obtained by adding the aqueous and the atmospheric pressures as above deduced. From Figs. 2 and 3 (Pl. XV), it will be seen that the annual variation of the height of sea surface is on the whole opposite to that of the atmospheric pressure; the sea water being lowest in March, and the barometric height maximum in the same month. The total pressure at the sea bottom varied relatively between 110 and 308 mm, the maximum and minimum occurring respectively in Octobor and March.

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* Reduced to sea level and the freezing point.

Table IV gives the data for 1902, meaned from Ayukawa and Misaki, as well as the total pressure at the sea bottom averaged from the two years 1902 and 1903. As will be seen from Fig. 8, the annual variation of the latter quantity presents the maximum in October and the minimum in March and April, the amount of fluctuation being 194 mm of water column, or 14.3 mm of mercury, which is about 1½ times that of the fluctuation of the monthly mean of the barometric pressure.

Table III. Mean Relative Monthly Heights of Sea Level and Barometric Pressure. ***Ayukawa*** and ***Misaki***. **1903**.

Month.	Height of Sea Level.	Barometric Pressure.	Total Pressure at Sea Bottom.*
	mm	mm	mm
January.	110	6.6	200
February.	62	6.9	156
March.	0	8.1	110 (min.)
April.	4	7.2	112

* Expressed in column of water.

Month.	Height of Sea Level.	Barometric Pressure.	Total Pressure at Sea Bottom*.
	mm	mm	mm
May.	103	4.1	159
June.	180	0.0	180
July.	214	0.8	225
August.	214	2.9	253
September.	212	4.9	279
October.	214	6.9	308 (max.)
November.	173	7.3	272
December.	154	5·6	230

Table IV. Mean Relative Monthly Heights of Sea Level and Barometric Pressure. ***Ayukawa*** and ***Misaki*.** **1902** and **1903.**

Month.	Height of Sea Level. 1902.	Barometric Pressure. 1902.	Total Pressure at Sea Bottom.* 1902.	Total Pressure at Sea Bottom.* 1902-1903 (mean.)
	mm	mm	mm	mm
January.	125	5.1	194	197
February.	0	8.3	111 (min.)	134
March.	46	6.0	128	119 (min.)
April.	74	4.0	128	120
May.	142	3.2	185	172
June.	171	0.2	174	177
July.	186	0.0	186	206
August.	205	2.6	240	247
September.	248	2.5	282	281
October.	210	7.9	317 (max.)	313 (max.)
November.	141	9.3	267	270
December.	207	4.8	272	251

---

* Expressed in column of water.

Comparing Figs. 2 and 3 with the figures in the 1st paper (the *Publications*, No. 18), we see that the relation of the variation of the height of sea surface to that of the atmospheric pressure remained essentially identical in the two years of 1902 and 1903, the only difference being that the epoch of the lowest water and highest barometer occurred in 1902 in February, and in 1903 in March.

In 1902, the amount of the fluctuation of the mean monthly values of the height of sea surface was 248 mm, while that of the atmospheric pressure was equivalent to 126 mm of column of water; these two numbers being in the ratio of 197 : 100. In 1903, the amount of fluctuation of the height of sea water was somewhat smaller, namely, 214 mm, that of the atmospheric pressure being also smaller and equivalent to 110 mm of water column. These two latter numbers are in the ratio of 195 : 100, which is nearly equal to that for 1902.

Observation at Choshi (1904)*. The following table gives the mean monthly values of the relative height of sea surface and the atmospheric pressure at Choshi, near the Cape Inuboe, in the province of Shimosa.

Table V. Mean Monthly Height of Sea Surface and Barometric Pressure at ***Choshi. 1904.***

Month.	Height of Sea Surface.	Barometric Pressure.‡
January.	27 mm	700 mm + 62.6 mm
February.	0	63.6

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* This account of the Choshi observation was also given in the "Tokyo Sugaku Butsuri Gakkwai Kiji Gaiyo," Vol. I.

‡ With gravity, sea level, and freezing point corrections.

Month.	Height of Sea Surface.	Barometric Pressure.
March.	75 mm	62.1 mm
April.	27	63.4
May.	78	59.3
June.	48	57.8
July.	130	57.7
August.	190	58.5
September.	236	58.3
October.	215	61.4
November.	72	61.2
December.	33	61.9

The above figures relating to the height of sea level and the barometric pressure have been deduced from the reading at 6 a.m. each day, during the year 1904. As will be seen from the above table, which is illustrated in Figs. 4 and 5 (Pl XVI), the sea surface was highest in September and lowest in February, while the barometric pressure was highest in February and lowest in June to September; the annual variation of the two quantities being approximately the reverse of each other, as was the case with Ayukawa and Misaki.

The difference between the mean monthly maximum and minimum heights of the sea surface was 236 mm, while that of the atmospheric pressure was equivalent to 86 mm of water column; these two numbers being in the ratio of 275 : 100.

***Japan Sea coast*[*]**. The annual variation of the height of sea surface considered in the preceding §§ relates to three places

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[*] An account of the Japan Sea coast observations has been given in the "Tokyo Sugaku Butsuri Gakkwai Kiji Gaiyo," in 1905.

on the Pacific coast of Japan. Let us now consider the same subject relative to the Japan Sea coast, there being on the latter the following four mareograph stations :—

- (i) Hamada, in the province of Iwami;
- (ii) Wajima, on the northern coast of the Peninsula of Noto;
- (iii) Iwasaki, on the western coast of the province of Mutsu;
- (iv) Otaru, in the province of Shiribeshi (Hokkaido).

Table VI gives the mean monthly values of the distance between the sea surface and the datum line in the mareogram at each of the above mentioned places; Table VII giving the mean monthly barometric pressures during the same year observed at the meteorological observatories of Hamada, Wajima, Aomori, and Sapporo. The two last cities have been chosen on account of their proximity respectively to Iwasaki and Otaru, there being no meteorological observatory at these two latter places. Finally, Table VIII gives the mean monthly values of the relative height of sea surface and of the atmospheric pressure, deduced from Tables VI and VII respectively.

Table VI. Mean Relative Monthly Position of the Sea Surface.
Japan Sea coast. 1902.

Month.	Relative distance between the sea surface and the datum line of the Mareogram.				
	Hamada.	Wajima.	Iwasaki.	Otaru.	*Mean.*
January.	307 mm	226 mm	180 mm	159 mm	218 mm
February.	396	330	317	278	330
March.	319	305	277	225	282

Month.	Relative distance between the sea surface and the datum line of the mareogram.				
	Hamada.	Wajima.	Iwasaki.	Otaru.	*Mean.*
April.	307 mm	289 mm	211 mm	162 mm	242 mm
May.	149	154	135	119	139
June.	117	109	136	93	114
July.	83	69	112	103	92
August.	34	25	79	79	54
September.	0	0	0	70	18
October.	112	73	107	0	73
November.	206	180	170	66	156
December.	192	158	155	89	149

Table VII. Mean Monthly Barometric Pressure*.

Japan Sea coast. 1902.

Month.	Hamada.	Wajima.	Aomori.	Sapporo.
January.	764.4 mm	763.6 mm	760.3 mm	757.22 mm
February.	66.5	66.1	63.3	60.09
March.	62.5	63.1	61.6	59.27
April.	60.6	61.2	58.4	55.20
May.	57.5	58.7	58.3	56.32
June.	54.4	56.1	56.1	62.23
July.	55.0	55.7	56.0	55.06
August.	55.8	57.4	59.0	57.78
September.	56.5	57.1	58.7	57.90
October.	63.8	64.2	64.3	62.24
November.	65.1	65.7	65.1	62.79
December.	62.5	62.2	61.1	59.66

---

* Reduced to the freezing point and the sea level.

Table VIII. Comparison of the Height of Sea Surface with the Barometric Pressure.

***Japan Sea coast.* 1902.**

Month.	Relative Height of Sea Surface.	Relative Barometric Pressure.	Relative Total Pressure at the Sea Bottom.
	mm	mm	mm
January.	112	5.94	193
February.	0	8.76	119
March.	48	6.17	132
April.	88	3.41	134
May.	191	2.26	222
June.	206	1.77	230
July.	238	0.00	238
August.	276	2.05	304
September.	312	2.11	341
October.	257	8.20	368
November.	176	8.98	298
December.	181	5.93	262

As will be seen from Table VI, the sea-level was lowest in February, and highest in September or October. The annual amounts of fluctuation of the mean monthly height of sea-level at Hamada, Wajima, Iwasaki and Otaru were respectively 396, 330, 317, and 278 mm, decreasing from the south to the north.

From Table VIII, the annual variation of the barometric pressure will be seen, as in the case of the places on the Pacific coast, to be nearly the reverse of that of the height of sea-level. Now the amount of fluctuation of the mean monthly barometric pressure, averaged from the observations at Hamada, Wajima, Aomori, and Sapporo, was 8.98 mm, which corresponds to 8.98 × 13.6 = 122 mm height of water. On the other hand, the annual fluctuation of the mean monthly height of sea-level, averaged from the observations at the four places of Hamada, Wajima, Iwasaki, and Otaru, was 312 mm. Along the Japan Sea coast, therefore, the fluctuation of the height of sea surface was opposite to, and nearly 2.6 times larger than, the corresponding fluctuation of the barometric pressure. In other words, the sea bottom is subjected to a greater total pressure in the summer months than in February, March, and April, the difference between the maximum and minimum total pressures being equal to 249 mm of water column, which is equivalent to 18.3 mm of mercury, and almost exactly twice the amount of fluctuation of the barometric pressure. The results containnd in Table VIII are illustrated in Figs. 6,7, and 9.

Comparison of the observations on the Pacific and Japan Sea coasts. According to the observations in 1902, the variations during the year of the height of sea surface and the barometric pressure on the Pacific and Japan Sea coasts were as follows :—

(A). Amount of Fluctuation of the Mean Monthly Values. **1902.**

Place.	Barometric Pressure. (mercury column)	Height of Sea Surface. (water column)	Total Pressure at Sea Bottom. (water column)
Pacific Coast. (Ayukawa and Misaki)	9.3 mm	248 mm	206 mm
Japan Sea Coast (Hamada, Wajima, Iwasaki, Otaru).	8.98	312	249

Again from the observations in 1903 and 1904, we obtain the following results.

(B). Amount of Fluctuation of the Mean Monthly Values.
Pacific Coast. **1903** and **1904.**

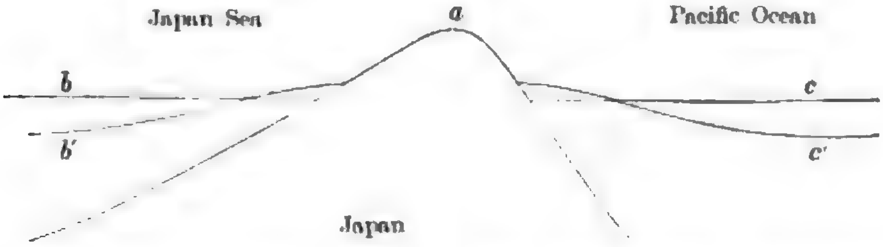
Place	Barometric Pressure.	Height of Sea Surface.	Total Pressure at Sea Bottom.
	(mercury column)	(water column)	(water column)
Ayukawa, Misaki.. ....1903.	8.1 mm	214 mm	198 mm
Choshi ......1904.	6.3	236	224

The relation between the height of sea surface and the barometric pressure, which may change from year to year depends without doubt on geogralphical features of a given coast. But. according to the two above tables, the different fluctuations were contained within fairly uniform limits, the annual variation of the height of sea surface being from 214 to 312 mm, and that of the total pressure at the sea bottom from 198 to 249 mm. There was no marked difference in these respects between the Pacific and Japan Sea coasts. Taking the simple averages from (A) and (B), we obtain the following mean values of the annual variation:—

Barometric Pressure..........8.17 mm of mercury = 111 mm of water.
Height of Sea Surface........253 mm of water.
Total Pressure at Sea Bottom..219 mm of water.

Thus the amount of fluctuation of the total pressure at the sea bottom was 219 mm, which is greater than that of the barometric pressure in the ratio of 197 : 100, or very nearly in the ratio of 2 : 1. The sea bottom pressure is maximum in October or September, and minimum in February to April.

The increase during the summer months in the height of sea level, as above described, is to be explained, partly by the fall in that epoch of the year of the barometric pressure over Japan and the neighbouring seas, and partly by the presence of a high pressure centre on the northern Pacific in the vicinity of the Aleutian Islands. Thus, if *b* and *c* (see the annexed diagram) represents the normal, or mean, level of the sea, the latter will be depressed to *b′* and *c′* through the influence of the high pressure area at *c*, and elevated along the coasts of Japanese Islands under the influence of the low pressure at *a*, the resulting equilibrium surface of water being a curved form, *b′* and *c′*. Similarly the decrease of the height of sea level in the winter months is to be explained by the rise of the barometric pressure over Japan and the presence of a low pressure centre on the Northern Pacific. It is probable that the co-existence of the centres of high and low barometric pressures respectively over the land and the ocean (or *vice versa*) causes, by the superposition of the effects, the amount of the annual variation of the height of sea to be approximately double that of the atmospheric pressure.



Seismic frequency and total pressure at sea bottom. To compare the annual variation of the frequency of earthquakes of submarine origin with that of the total pressure at sea bottom, I indicate in the following table the mean monthly percentage numbers of earthquakes for Nemuro, Miyako, Ishinomaki, Kochi, and Hamada; the figures being based on the data given in the "Publications of the Earthquake Inv. Comm.", No. 8. Of these five places, each of which is disturbed mostly by earthquakes of submarine origin, the first four are situated on the Pacific coast of Japan, and the remaining one on the Japan Sea coast.

Table IX. Annual Variation of Seismic Frequency.

Month.	Nemuro.	Miyako.	Ishinomaki.	Kochi.	Hamada.	*Mean.*
January.	6.5	6.2	4.1	6.9	6.8	5.9
February,	6.5	4.4	5.7	11.7	6.8	6.5
March.	7.7	8.1	5.3	9.3	6.8	7.8
April.	7.8	10.0	8.1	9.3	3.3	8.1
May.	9.4	6.9	8.1	4.8	3.3	7.1
June.	9.4	9.0	7.5	10.5	3.3	8.2
July.	9.6	12.2	11.5	8.1	3.3	9.8
August.	8.0	12.1	13.2	6.9	13.3	10.9
September.	8.4	5.3	10.5	5.7	10.0	8.0
October.	9.4	9.7	8.4	8.1	20.0	10.4
November.	8.4	9.0	11.0	8.1	10.0	9.4
December.	8.8	6.9	6.8	10.5	13.3	8.6

The mean seismic frequency, given in the last column of the above table, has been deduced from the figures for the five different places; the weight of the data relating to Kochi and

Hamada, whose earthquake numbers were not numerous enough, being taken as half of that for the others. The annual variation of the mean seismic frequency thus obtained is illustrated in Fig. 11, while that of the relative total sea bottom pressure, deduced by taking the means of the results relating to the Pacific and Japan Sea coasts is illustrated in Fig. 10.

From a comparison of Figs. 10 and 11, it will be seen that the frequency of submarine earthquakes follows, on the whole, the variation of the total pressure at the sea bottom. Thus, the earthquake number is minimum in January and February, and maximum in August, and the sea bottom pressure is minimum in February to April, and maximum in September and October.

Stronger earthquakes of submarine origin. The seismic frequencies considered in the preceding § relate essentially to small ordinary, or non-destructive, earthquakes and may therefore, in their annual variation, be different from those of shocks which are large. Thus, for instance, taking the 319 stronger earthquakes, which happened between 1902 and 1906 off the coasts of Japan, and whose land area of disturbance was, with a few exceptions, greater than 1,000 square *ri*[*], we find:—

Table X. Annual Variation of Stronger Submarine Earthquakes.

Month.	Number of Eqkes.	Month.	Number of Eqkes.
January.	25	July.	38
February.	39	August.	27
March.	25	September.	22
April.	19	October.	28
May.	28	November.	20
June.	21	December.	27

---

[*] 1 *ri* = 3.927 km. nearly.

The annual variation of these larger submarine earthquakes, illustrated in Fig. 12, indicates the maximum in February, and is, on the whole, opposite to that of the small shocks.

Pl. XIV.

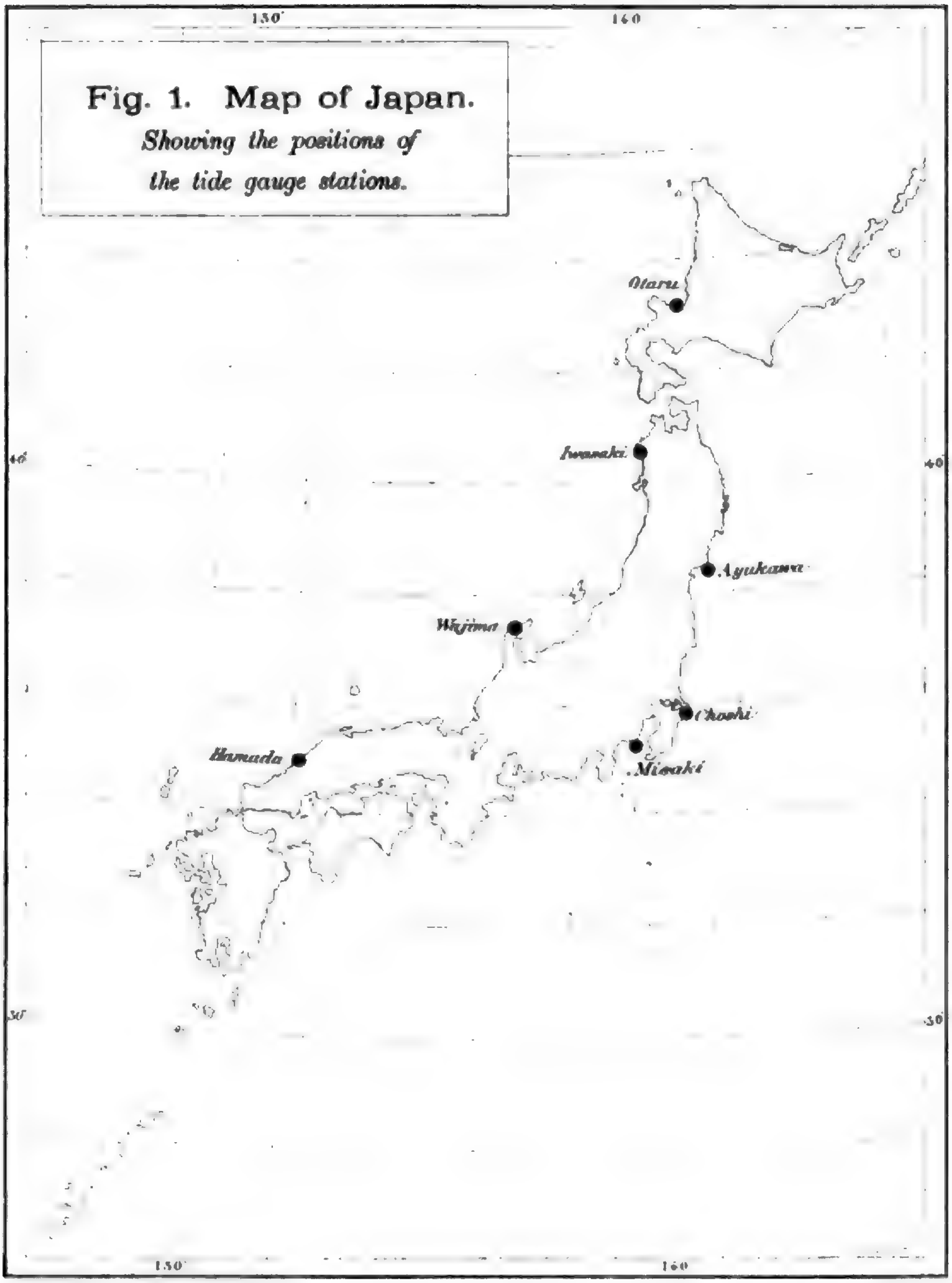


Fig. 1. Map of Japan.

Showing the positions of the tide gauge stations.

130°
140
Otaru
Iwasaki
40
40
Ayukawa
Wajima
Choshi
Hamada
Misaki
30
30
130°
140

Annual Variation of the Height of Sea Surface and the Atmospheric Pressure.

Japan Sea Coast, 1902.

Fig. 6. Atmospheric Pressure.

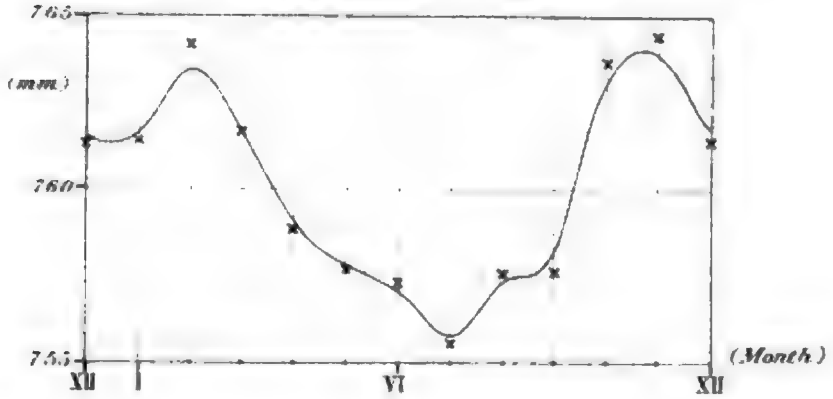
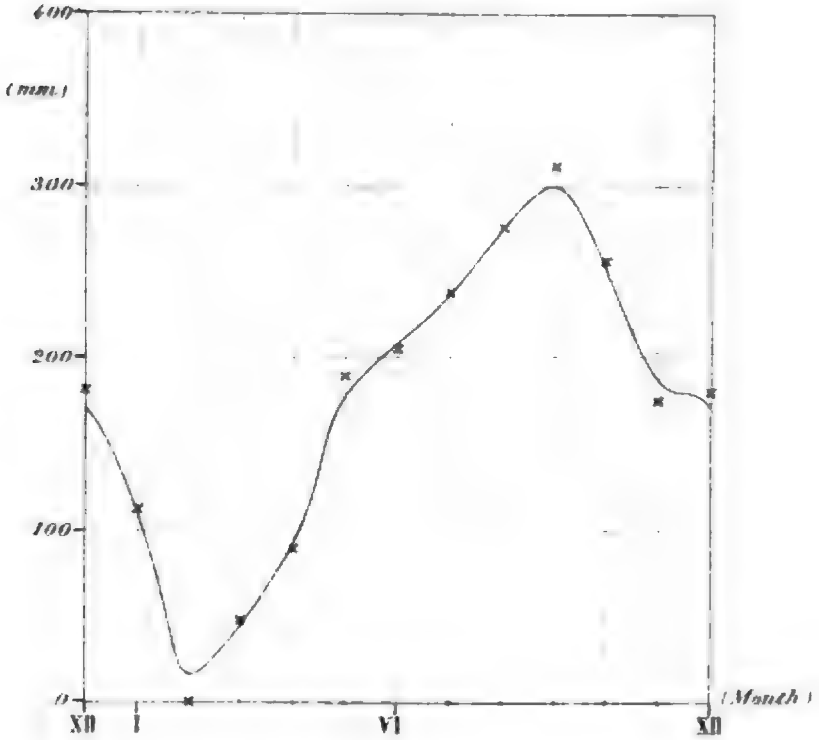


Fig. 7. Height of Sea Surface.



Annual Variation of the Total Pressure at the Sea Bottom.

Fig. 8. *Ayukawa* and *Misaki.* *1902–1903.*

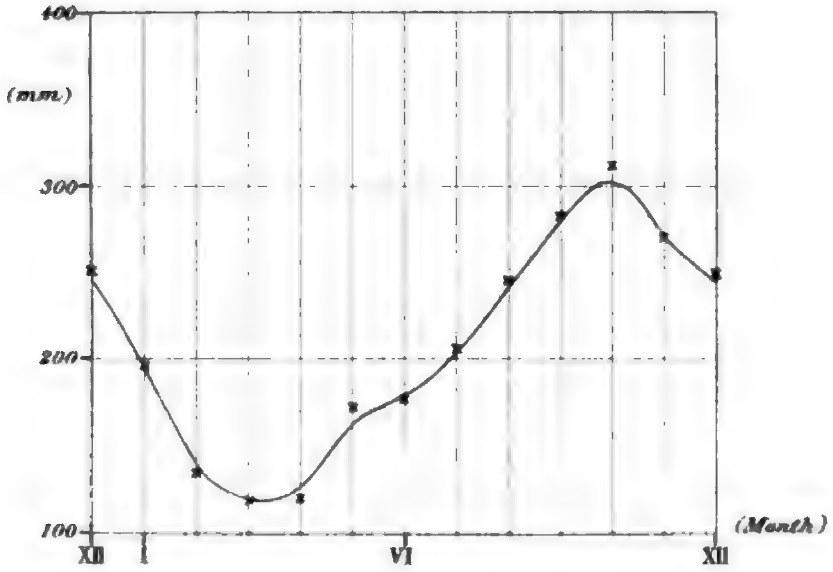
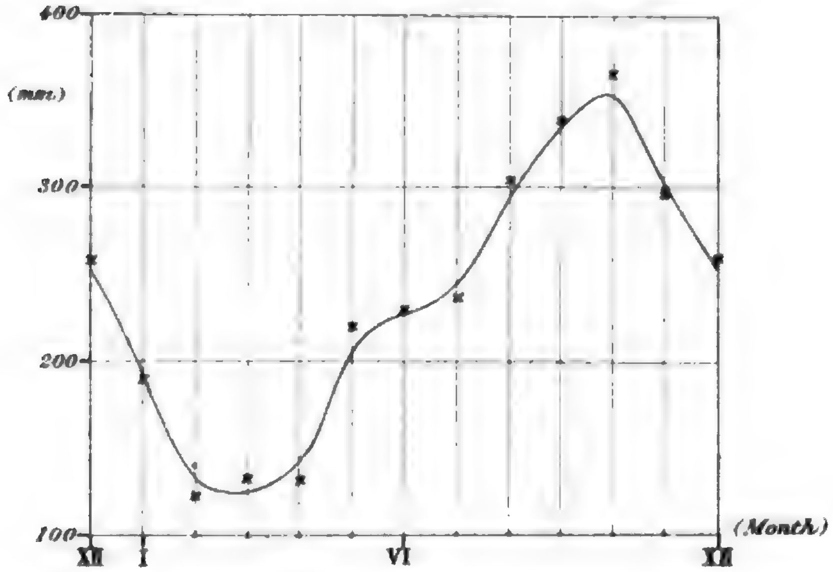


Fig. 9. *Japan Sea Coast.* *1902.*



Annual Variation.

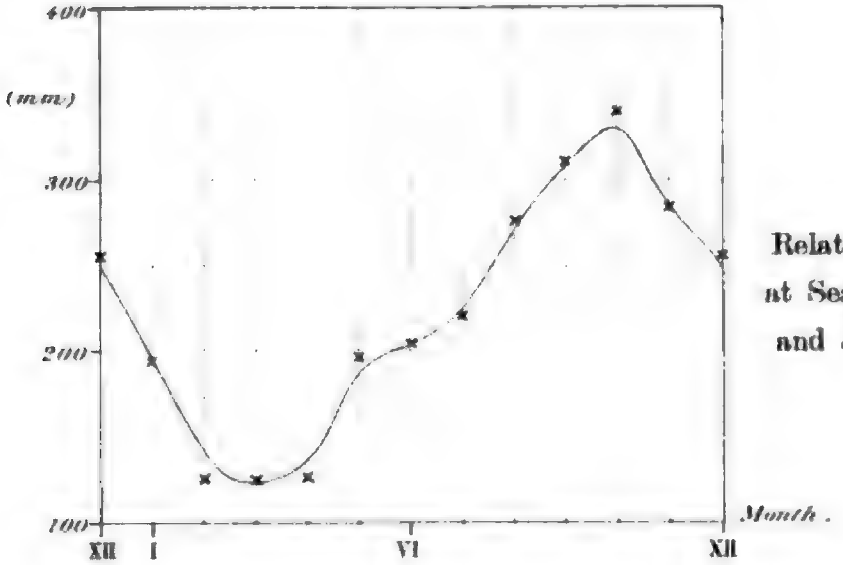


Fig. 10.
Relative Total Pressure at Sea Bottom. (Pacific and Japan Sea Coast.)

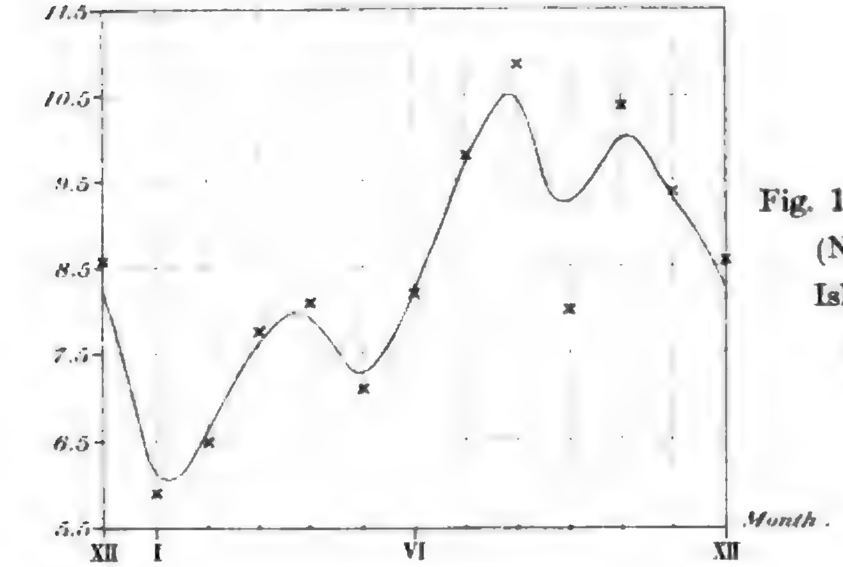


Fig. 11. Eqke Frequency. (Nemuro, Miyako, Ishinomaki, Kochi, and Hamada).

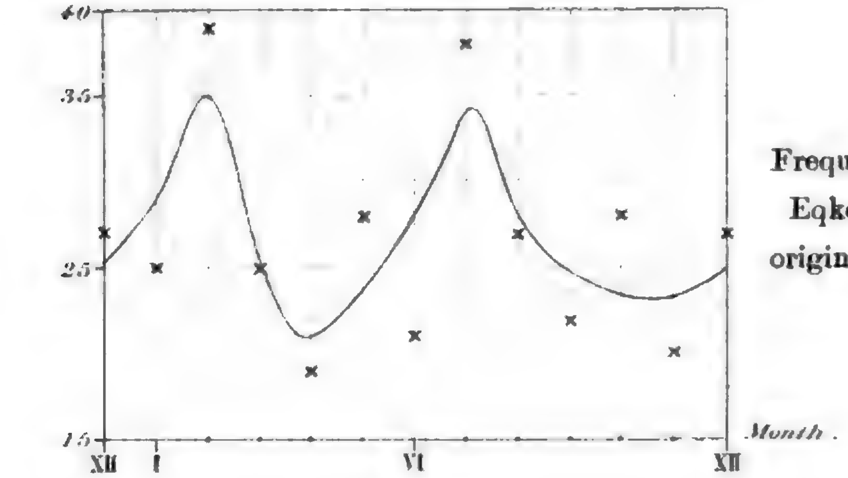


Fig. 12.
Frequency of Stronger Eqkes of submarine origin. (Whole Japan.)

Note on the Annual Variation of the Height of Level of Lake Biwa.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls XX-XXI.

The Lake of Biwa[*], in the province of Omi, is the largest of the sort in Japan and is situated near the middle of the Main Island; its surface being about 86 metres above the mean sea level, and its area 46.5 square *ri*[‡], or 717.2 sq. km. The observation of the water level along the coast of the lake was made, during the 12 years, 1893-1904, at 22 stations, to which, since 1905, nine more were added; the datum line being 282.53 *shaku* or 85.61 metres above the mean sea level at Tenpo-san, Osaka. The mean height of the surface of the lake water for each month during the 14 years, 1893-1906, obtained by taking the average of the measurements at the different places, is given in Table I.

From Table I it will be observed that the water was highest mostly in December and January; the amount of the fluctuation, or the difference between the maximum and minimum monthly heights, varying between 8.18 *shaku* (=248 cm) and 1.40 *shaku* (=42 cm.). The extreme monthly heights of the water level and their difference in each of the 14 years under consideration are given in Table II.

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[*] An account of the earthquake zones around the Biwa Lake has been given in the *Bulletin*, Vol. I, No. 3.

[‡] 1 *ri* = 36 *chō* = 2.1 miles, or 3.927 km.

Table I. Mean Monthly Height of the Level of Lake Biwa*. 1893–1906.

Month. / Year.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Mean.*
1893	2.74	2.82	2.68	3.71	3.93	3.90	2.62	1.76	2.00	2.69	2.86	2.41	2.84
1894	2.24	2.15	2.49	3.44	3.47	2.30	1.35	0.77	0.66	0.28	0.20	0.28	1.64
1895	0.61	0.98	2.01	2.39	1.78	1.49	3.12	6.18	3.99	2.84	2.10	1.44	2.41
1896	1.56	1.79	2.34	3.23	3.26	2.42	3.02	5.63	9.74	7.22	4.51	3.73	4.20
1897	3.05	2.92	2.67	3.52	3.98	3.05	2.80	2.05	2.59	3.72	2.24	1.77	2.86
1898	1.90	2.30	2.40	2.28	1.95	2.12	2.69	1.52	1.71	1.50	0.93	1.13	1.87
1899	1.67	2.19	3.45	3.07	2.21	2.02	2.15	1.83	3.18	4.29	2.95	1.79	2.57
1900	1.49	1.62	1.60	2.72	3.16	1.93	1.76	1.62	1.80	2.77	2.23	1.90	2.05
1901	1.74	1.48	1.25	1.71	1.44	0.76	2.56	1.70	0.83	0.24	0.17	0.04	1.16
1902	-0.05	0.06	0.47	1.10	2.23	1.99	1.62	2.33	1.15	1.23	0.41	-0.11	1.01
1903	0.31	1.78	0.83	2.10	2.40	2.34	4.27	2.90	0.52	0.56	0.35	0.43	1.56
1904	0.45	0.24	0.58	0.48	0.91	0.91	2.22	1.24	1.52	1.92	0.94	0.80	1.02
1905	1.33	1.11	1.69	1.37	1.17	1.29	2.93	2.30	1.73	0.37	0.08	-0.02	1.30
1906	1.00	1.55	1.90	1.27	0.61	0.67	2.01	1.17	1.05	1.55	1.25	0.78	1.23
Mean.	1.43	1.66	1.88	2.31	2.32	1.94	2.65	2.36	2.32	2.23	1.52	1.17	1.98

* The heights are expressed in *shaku* (1 *shaku* = $^1/_{3.3}$ metre), the datum line being 282.53 *shaku* above the mean sea level at Tenposan, Osaka.

PL. XX.

Annual Variation: the Height of Surface of Lake Biwa compared with the Amount of Precipitation and Barometric Pressure.

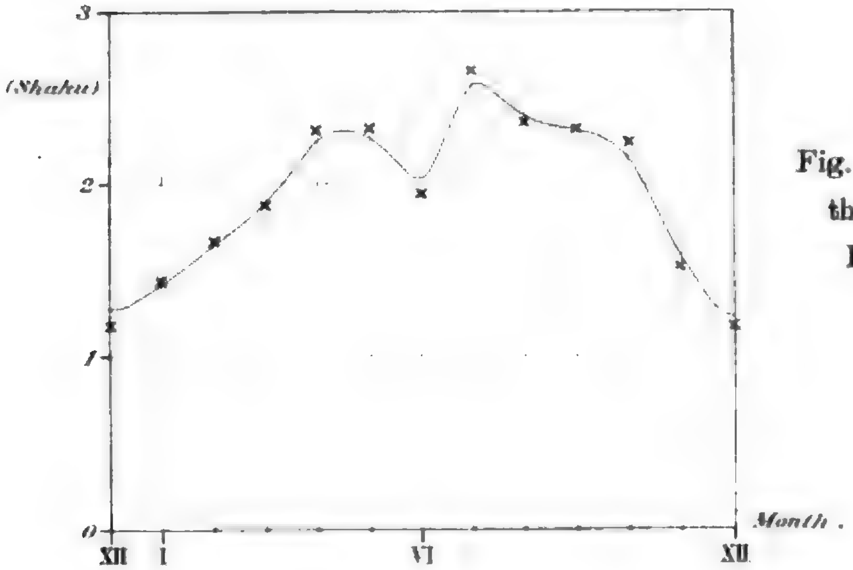

Fig. 1. Height of the Surface of Lake Biwa.

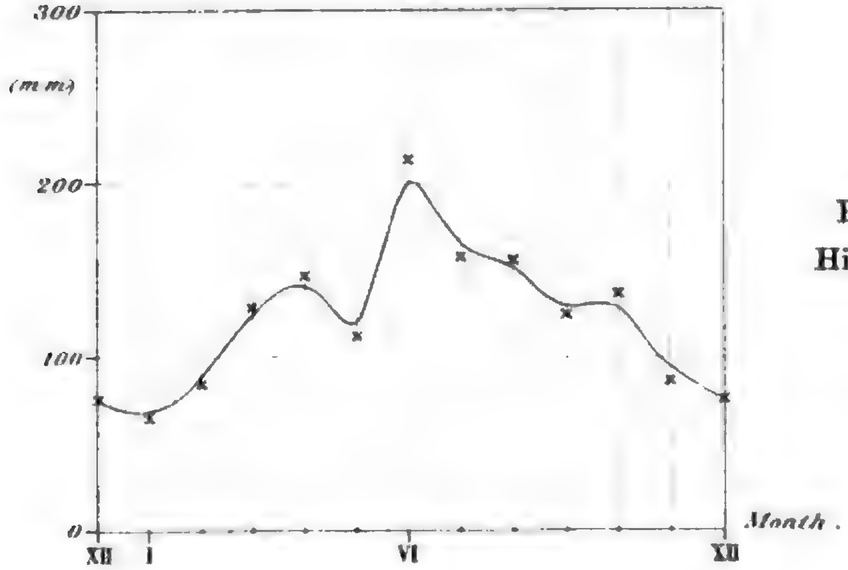

Fig. 2. Precipitation at Hikone and Kyoto

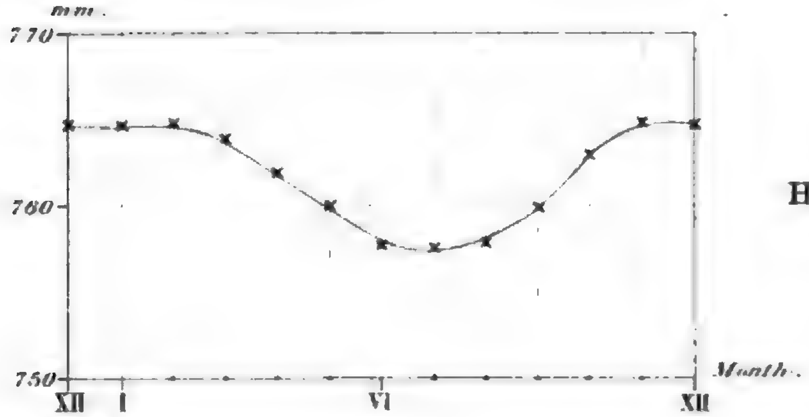

Fig. 3. Barometric Height at Hikone.

Annual Variation of the Seismic Frequency and the Pressure at the Lake Bottom.

Fig. 4. Seismic Frequency at Hikone.

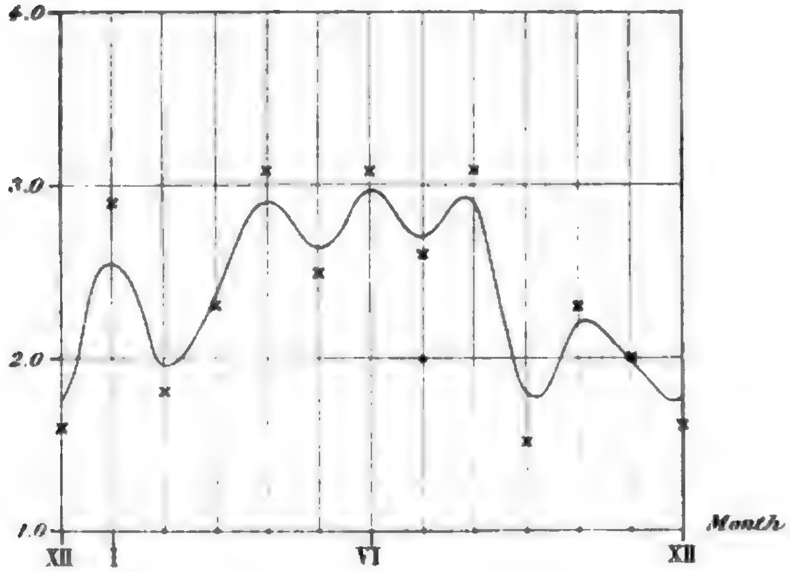

Fig. 5. Total Pressure at the Lake Bottom.

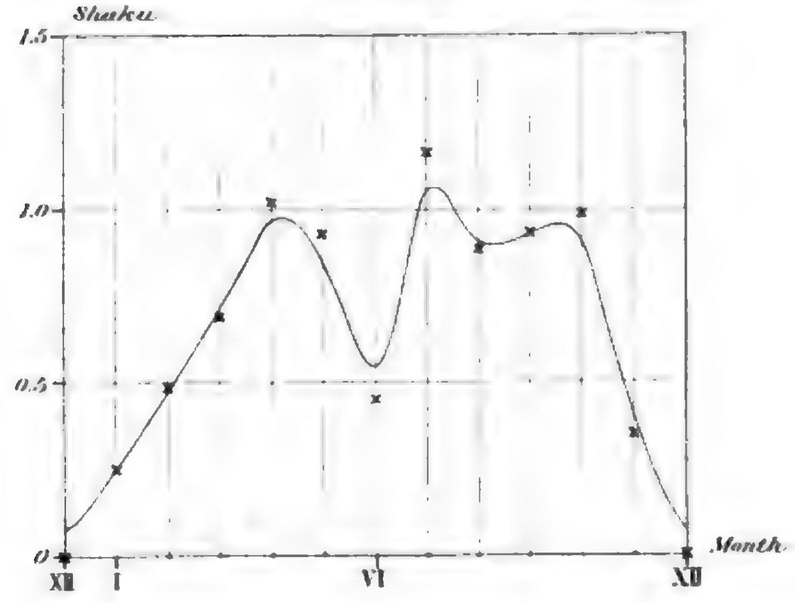

Table II. Maximum and Minimum Heights of the Lake Water.

Year	Maximum Height.		Minimum Height.		Difference.
	shaku		shaku		shaku
1893	3.93	(May)	1.76	(Aug.)	2.17
1894	3.47	(,,)	0.20	(Nov.)	3.27
1895	6.18	(Aug.)	0.61	(Jan.)	5.57
1896	9.74	(Sept.)	1.56	(,,)	8.18
1897	3.98	(May)	1.77	(Dec.)	2.21
1898	2.69	(July)	0.96	(Nov.)	1.73
1899	4.29	(Oct.)	1.67	(Jan.)	2.62
1900	3.16	(May)	1.49	(,,)	1.67
1901	2.56	(July)	0.04	(Dec.)	2.52
1902	2.33	(Aug.)	−0.11	(,,)	2.44
1903	4.27	(July)	0.31	(Jan.)	3.96
1904	2.22	(,,)	0.24	(Feb.)	1.98
1905	2.93	(,,)	0.02	(Dec.)	2.95
1906	2.01	(,,)	0.61	(May)	1.40

In the following table I give the average heights of the lake water for the different months of the year deduced from Table I, and also the mean monthly barometric heights observed at the meteorological observatory of Hikone, which is situated on the south-eastern coast of Lake Biwa.

Table III. Annual Variations of the Height of Lake Water, and of the Barometric Pressure at Hikone.

Month.	Lake Level		Barometric Pressure.			Total pressure at the Lake Bottom.	
	(i) mean Height.	(ii) Relative Height.	(iii) Monthly mean.	(iv) Variation.	(v) Same as (iv), expressed in equivalent column of water.	(vi) Sum of (ii) and (v)	(vii) Relative Variation.
	shaku	shaku	mm	mm	shaku	shaku	shaku
I	1.43	**0.26**	764.5	6.9	0.31	0.57	**0.25**
II	1.66	**0.49**	64.7	7.1	0.32	0.81	**0.49**
III	1.88	**0.71**	63.9	6.3	0.28	0.99	**0.67**
IV	2.31	**1.14**	61.9	4.3	0.19	1.33	**1.01**
V	2.32	**1.15**	59.8	2.2	0.10	1.25	**0.93**
VI	1.94	**0.77**	57.6	0.0	0.00	0.77	**0.45**
VII	2.65	**1.48**	57.6	0.0	0.00	1.48	**1.16**
VIII	2.36	**1.19**	57.8	0.2	0.01	1.20	**0.88**
IX	2.32	**1.15**	59.8	2.2	0.10	1.25	**0.93**
X	2.23	**1.06**	63.0	5.4	0.24	1.30	**0.98**
XI	1.52	**0.35**	64.8	7.2	0.32	0.67	**0.35**
XII	1.17	**0.00**	64.7	7.1	0.32	0.32	**0.00**

With regard to the annual variation of the lake level, we see, from (ii), Table III, that the difference between the maximum and minimum monthly heights was 1.48 *shaku* (=44.9 cm.), the corresponding change in the volume of the water of the lake being $10^8 \times 3.22$ cubic metres or about 0.322 cubic km.

As will be seen from the graphical illustration in Fig. 1 (Pl. XX), the level was higher in April to October than during the other months, and its annual variation is nearly opposite to that of the barometric pressure (Fig. 2). The amount of fluctuation of the monthly mean of the latter is, however, only 7.2 mm of mercury (=0.32 *shaku* of water), or about one-fifth of that of the former; the annual variation of the lake level depending probably almost entirely on the precipitation in the surrounding districts.

The following table gives the average monthly amount of precipitation at Hikone and at Kyoto, the latter place being situated some distance to the south-west of the Lake of Biwa.

Table IV. Precipitation at Hikone and Kyoto.

Month.	Hikone	Kyoto	*Mean*
January	76.8 mm	52.4 mm	64.6 mm
February	107.4	62.7	85.1
March	145.0	114.3	129.7
April	126.1	168.3	147.2
May	77.0	148.3	112.7
June	188.7	240.5	214.6
July	135.5	182.7	159.1
August	189.7	120.9	155.3
September	93.4	157.4	125.4
October	137.4	135.8	136.6
November	82.7	86.6	84.7
December	101.5	50.1	75.8

As illustrated in Fig. 2, the annual variation of the precipitation at Kyoto and Hikone is very similar to that of the height of the lake surface (Fig. 1).

Annual variation of seismic frequency at Hikone. The monthly number of earthquakes observed instrumentally at the meteorological observatory of Hikone, between 1894 and 1907, are as follows.

Table V. Monthly Earthquake Numbers at Hikone.

Month. / Year.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Sum.*
1894	20*	6	3	0	2	7	8	9	1	4	3	6	69
1895	11	1	2	6	2	1	5	1	7	7	2	6	51
1896	4	1	2	10	6	13	9	8	1	1	1	2	58
1897	3	3	4	7	3	1	0	6	1	2	1	0	31
1898	1	0	0	2	0	0	0	4	0	1	2	0	10
1899	3	2	6	2	5	2	1	0	0	0	4	1	26
1900	1	0	2	1	2	3	2	1	3	6	7	3	31
1901	2	2	1	1	1	1	2	0	2	0	4	0	16
1902	2	1	3	0	2	4	2	1	2	1	1	0	19
1903	1	1	3	0	0	0	4	1	0	0	1	1	12
1904	1	0	1	1	2	3	0	1	1	1	1	0	12
1905	1	1	1	0	0	4	0	5	1	4	0	3	20
1906	6	3	1	5	5	1	3	5	1	2	0	0	32
1907	2	4	3	8	5	4	1	1	1	3	1	0	33
Mean.	2.9	1.8	2.3	3.1	2.5	3.1	2.6	3.1	1.5	2.3	2.0	1.6	

As shown in Fig. 4 (Pl. XXI), the annual variation of the seismic frequency at Hikone indicates the maximum in August, differing in this respect from those for the other stations, such as Kyoto, Nagoya, and Kumamoto, which are shaken more by earthquakes of inland origin, and whose seismic frequency is generally minimum in Summer‡. Now, according to Table III, the total pressure at the lake bottom, or the sum of the water and atmospheric pressures, is maximum in July, and its annual variation is somewhat similar to that of the height of the water level. The change of pressure at the bottom of the lake, whose mean annual amplitude is 1.16 *shaku* (=35 cm), or 3.6 times greater than that of the barometric pressure, may possibly be the cause of the annual variation of the seismic frequency peculiar to Hikone.

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* Excluded in deducing the mean frequency, being due to the abundance of after-shocks of the severe Mino-Owari earthquake of Jan. 10, 1894.

‡ See the "Publications," No. 8.

List of the Stronger Japan Earthquakes, 1902-1907.

By

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The total number of earthquakes, which originated in or about Japan during the last six years, 1902 to 1907, was 9,628, giving the average yearly frequency of 1,605, as follows .—

Year.	Number of eqkes.
1902	1,488
1903	1,349
1904	1,230
1905	1,963
1906	1,792
1907	1,806

Among these earthquakes which were mostly slight and local, there were 621*, which were extensive, and whose land area of motion, as observed with ordinary Gray-Ewing-Milne type seismographs, was over 1,000 square *ri* (1 *ri*=3.927 km). The annual frequency of these larger earthquakes varied between 76 and 132, as follows :—

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* Including a few typical earthquakes of inland origin, whose area was between 500 and 1,000 sq. *ri*.

Monthly and Yearly Numbers of Larger Earthquakes.

Whole Japan. 1902—1907.

Year. Month.	1902	1903	1904	1905	1906	1907	*Sum.*
January.	10	5	2	7	14	7	45
February.	13	11	2	14	8	5	53
March.	11	10	10	6	20	15	72
April.	4	5	9	7	14	12	51
May.	13	2	10	5	19	9	58
June.	5	4	9	29*	3	4	54
July.	8	10	13	14	7	8	60
August.	4	7	8	9	10	6	44
September.	8	8	6	13	5	8	48
October.	4	3	8	12	12	11	50
November.	7	5	6	5	10	9	42
December.	8	6	6	11	6	7	44
Sum.	95	76	89	132	128	101	621

The unusually large monthly number of 29 for June 1905 (marked with an *asterisk*) was due to the occurrence of the strong O-shima and Inland Sea earthquakes and their after-shocks. The average yearly seismic frequency is about 104, or at the rate of nearly twice per week.

The land area of sensible motion of the 621 earthquakes under consideration varied between about 100 sq. *ri* to over 20,000 sq. *ri*, the numbers of the shocks of different extension being as shown in the following table.

Numbers of Earthquakes of Different Land Areas of *Sensible Motion.*

Land area of sensible motion.	Number of earthquakes.	Land area of sensible motion.	Number of earthquakes
under 500 sq. ri.	58	7,501— 8,000 sq. ri.	6
501—1,000	112	8,001— 8,500	7
1,001—1,500	86	8,501— 9,000	4
1,501—2,000	82	9,001— 9,500	1
2,001—2,500	59	9,501—10,000	1
2,501—3,000	36	10,001—10,500	3
3,001—3,500	35	10,501—11,000	4
3,501—4,000	23	11,001—11,500	1
4,001—4,500	22	11,501—12,000	2
4,501—5,000	16	12,001—12,500	1
5,001—5,500	15	12,501—13,000	0
5,501—6,000	19	13,001—13,500	0
6,001—6,500	8	13,501—14,000	1
6,501—7,000	10	14,001—14,500	1
7,001—7,500	7	14,501—15,000	0
		⋮	⋮
		20,501—21,000	1

Confining our attention to those earthquakes, whose land area of *sensible* motion was over 500 sq. *ri*, we see from the above table that the areas of the majority of these are included between 501 and 6,000 sq. *ri*. Especially, the earthquakes of the area between 501 and 2,000 sq. *ri* were numerous, and their total number, namely, 280, is very nearly equal to that of all the shocks of the area between 2,001 and 21,000 sq. *ri*, namely, 283. Very extensive disturbances happened of course not very frequently, and there were only 16 earthquakes, whose area of sensible motion was over 9,001 sq. *ri*.

Pl. XXII graphically illustrates the variation of the frequency of earthquakes of the different land areas of sensible motion. The mean curve seems to be approximately a logarithmic curve, becoming quickly asymptotic with the increase of the area.

The accompanying list, which has been compiled, with a few corrections, from the seismological notes in the successive monthly numbers of the "Kisho Yoran" (*Weather Review*) published by the Central Meteorological Observatory, gives for each of the 621 strong and moderate earthquakes under question, the following particulars :—

(1). Date.

(2). Approximate time of earthquake occurrence at the epicentre. The time used is that of longitude 135° E. of Greenwich, namely, the 1st Normal Japan Time.

(3). Approximate indication of the position of the earthquake origin.

(4), (5). Longer and shorter axes of the land area, within which the motion was intense enough to be recorded by the ordinary Gray-Ewing-Milne type seismographs, the seismic disturbance being *sensible* only in a portion of the region thus determined.

(6). Land area of disturbance of *strong* motion.

(7). „ „ „ „ „ *moderate* „

(8). „ „ „ „ „ *slight* „

(9). Total land area, within which the earthquake motion was *sensible* this being equivalent to the sum of (6), (7), and (8).

The length and area are expressed in *ri* and square *ri* respectively. These may be converted into kilometers and miles by the following relations :—

$$\begin{cases} 1\ ri = 3.93\ \text{km} = 2.44\ \text{miles.} \\ 1\ \text{sq.}\ ri = 15.42\ \text{sq. km} = 5.96\ \text{sq. miles.} \end{cases}$$

For the names and positions of the different provinces, the reader is referred to the key map of Japan given in the "Bulletin," Vol. I, Pl. XXVII.

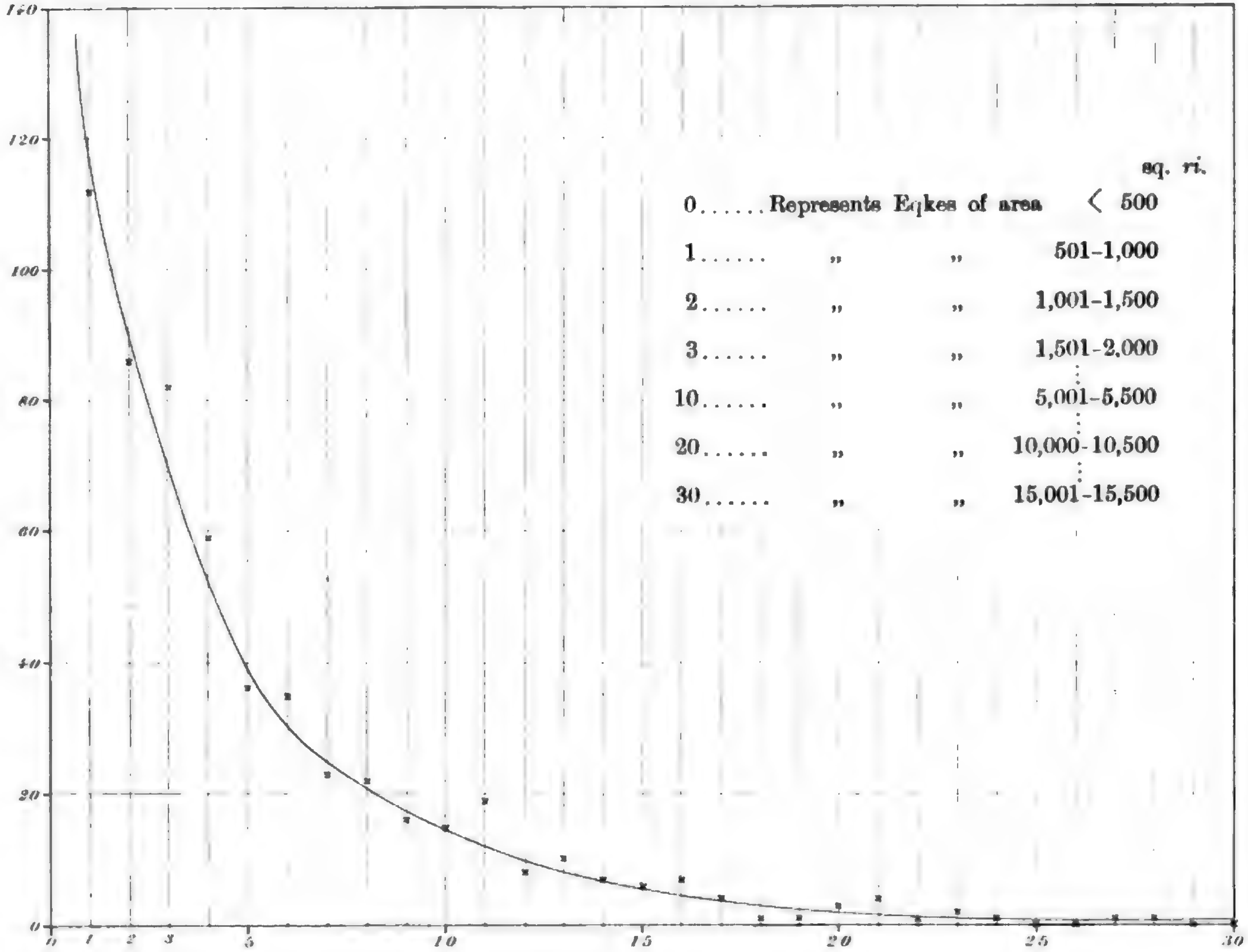
The intensity of ordinary, or non-destructive, sensible motion is here indicated as "strong," "moderate," or "slight." A "slight" shock is one which is very feeble and just strong enough to be felt; a "moderate" shock is one whose motion is well pronounced, but not so severe as to cause general alarm; and, finally, a "strong" shock is one which is sufficiently intense to cause people to run out of doors, to throw down furnitures, to produce slight cracks of walls, etc.

621 STRONGER JAPAN EARTHQUAKES. **1902-1907.**

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1902				*ri.*	*ri.*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Jan.	1	0^h20^m a.m.	Off the E. coast of Mutsu.	250	100	—	400	2,700	3,100
	3	1 40 a.m.	Boundary between Kii and Yamato.	140	80	190	380	1,230	1,800
	4	6 09 a.m.	Off the coast of Hitachi.	160	120	—	1,050	3,850	4,900
	5	4 04 p.m.	Vicinity of Mito (Hitachi).	70	60	—	250	1,500	1,750
	14	9 01 a.m.	S. part of Hida.	110	70	—	250	2,550	2,800
	17	4 18 a.m.	Central part of Sagami.	100	50	70	230	1,500	1,800
	18	4 38 a.m.	Off the E. coast of Mutsu.	250	150	200	1,900	4,850	6,950
	20	11 25 p.m.	" " coast of Hitachi.	200	100	—	1,450	5,600	7,050
	30	11 01 p.m.	" " E. coast of Mutsu. $\phi = 39°09'N, \lambda = 143°31'E.$	350	250	2,000	5,400	6,300	13,700
	31	10 42 a.m.	Off the coast of Mutsu. $\phi = 40°30'N, \lambda = 144°13'E.$	280	220	650	3,950	6,000	10,600

PL. XXII.

Frequencies of the Earthquakes whose Land Area of Sensible Motion was over 500 sq. *ri.*



(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1902			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Feb. 2	2^h52^m a.m.	Off the coast of Rikuchū.	120	60	—	280	1.620	1,900
6	7 18 a.m.	City of Kumamoto (Higo.)	60	20	—	460	510	970
,,	9 05 p.m.	,,	70	60	—	750	1,150	1,900
7	10 01 p.m.	Off the E. coast of Mutsu.	180	100	—	270	3,670	3,940
8	0 31 p.m.	,, of Nemuro.	80	50	190	40	460	690
11	11 50 p.m.	Bay of Owari.	40	20	—	190	420	610
17	8 30 p.m.	Off the coast of Hitachi.	100	80	—	580	1,380	1,960
20	10 50 a.m.	Hachijō-jima.	190	150	—	650	6,550	7.200
21	0 35 a.m.	Off the E. coast of Mutsu.	260	170	370	2,960	7 400	10,730
,,	8 29 a.m.	Do.	200	110	10	1,000	4,580	5,590
26	10 19 a.m.	Off the coast of Rikuchū.	190	130	—	770	2,660	3,430
27	0 01 p.m.	,, Hidaka.	130	80	—	220	2,330	2,550
,,	11 18 p.m.	,, Iwaki.	140	60	60	620	2,560	3,240
28	5 41 p.m.	N. part of Ise.	40	30	—	300	980	1,280
March 1	1 33 p.m.	Off the coast of Rikuchū.	140	120	—	380	2,640	3,020
,,	8 23 p.m	N. part of Yamato.	70	50	90	330	1,330	1,750
3	9 13 a.m.	Vicinity of Sahara (Shimosa).	180	160	—	1,500	6,550	8,050
,,	10 37 p.m.	Tsugaru Strait.	140	70	10	430	2,550	2,990
6	9 35 p.m.	Kii Channel.	50	30	90	190	650	930
10	2 35 p.m.	W. part of Hitachi.	150	120	—	2,000	3,970	5,970
12	10 48 a.m	Uraga Channel.	70	60	—	190	1,500	1,690
20	10 59 a.m.	Tainan (Formosa).	500	200	50	200	2,250	2,500
,,	11 19 a.m	Do.	200	100	—	600	1,400	2,000
23	6 17 p.m.	Central part of Settsu.	90	60	70	1,550	1.590	3,210
25	2 35 p.m.	Vicinity of Sahara (Shimosa).	220	180	240	2,520	5.150	7,910
April 1	5 32 a.m.	E. part of Sagami.	100	40	—	240	2,290	2,530

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum.
1902			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
April. 5	7h23m p.m.	Bay of Tôkyô. φ = 35° 26′ N, λ = 139° 45′ E	130	100	—	2,050	3,580	5,630
6	2 13 a.m.	Bay of Tôkyô. φ = 35° 31′ N, λ = 139° 49′ E	70	60	—	870	1,130	2,000
19	9 17 a.m.	N part of Mino.	70	50	30	270	1,450	1,750
May 2	8 31 p.m.	Off the coast of Rikuchu.	250	200	—	1,360	2,750	4,110
5	7 05 a.m.	Karita-county, Iwaki.	60	40	10	240	800	1,050
6	8 33 a.m.	Off the E. coast of Kii.	100	40	—	320	1,760	2,080
8	11 19 a.m.	Vicinity of Tanega-shima.	200	100	740	1,170	2,710	4,620
15	7 38 a.m.	Vicinity of Kasumiga-ura.	40	30	70	210	870	1,150
16	9 39 a.m.	Koshi-county, Echigo.	90	60	—	430	2,620	3,050
17	1 18 p.m.	Off the coast of Hitachi.	90	70	-	360	1,320	1,680
24	5 03 a.m.	S. part of Ise.	60	50	40	530	870	1,440
„	11 30 p.m.	N. part of Ise.	100	80	90	1,570	2,350	4,010
25	8 29 p.m.	Minamitsuru county, Kai.	160	130	390	1,620	3,810	5,820
„	9 07 p.m.	Do.	120	80	110	790	3,420	4,320
„	10 15 p.m.	Do.	70	50	70	370	1,610	2,050
28	6 02 p.m.	S. part of Kushiro	350	200	430	1,560	5,650	7,640
June 2	9 28 p.m.	Off the S. coast of Kii.	120	80	200	900	1,500	2,660
13	9 22 a.m.	Off the S. coast of Kushiro.	300	200	300	1,500	6.100	7,900
20	5 40 p.m.	Sano (Shimotsuke).	180	150	470	1,660	6,170	8,300
23	7 42 a.m.	Bay of Tokyô. φ = 35° 26′N, λ = 139° 50′E	190	160	450	1,830	5,220	7,500
29	2 29 a.m.	Off the coast of Rikuchu.	270	150	—	840	2,820	3,660
July 1	2 01 a.m.	N. part of Sagami.	100	80	—	540	2,800	3,340
„	5 19 p.m.	Off the coast of Rikuchu.	260	180	—	1,080	3,840	4,920
8	11 05 p.m.	„ E. coast of Mutsu.	300	200	160	1,840	6 000	8,000

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1902				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
July	9	2^h42^m a.m.	Off the coast of Amakusa (Higo).	50	40	—	470	900	1,370
	10	7 57 p.m.	" Mutsu	250	150	—	1,400	4,350	5,750
	11	8 57 a.m.	" Izu.	130	80	—	260	2,190	2,450
	"	10 03 a.m.	" NE coast of Nemuro.	300	150	—	200	3,200	3,400
	26	7 51 a.m.	" E coast of Awa peninsula.	180	100	—	380	3,170	3,550
Aug.	7	0 36 p.m.	Bay of Tokyo.	160	70	—	720	3,550	4,270
	"	6 22 p.m.	Off the coast of Mutsu.	250	150	—	280	5,320	5,600
	8	8 37 a.m.	Sahara (Shimosa).	200	120	60	480	3,890	4,430
	19	8 43 p.m.	Off the coast of Hidaka.	130	80	—	290	1,570	1,860
Sept.	3	11 55 a.m.	Off Kinkazan (Rikuzen).	150	100	10	600	2,790	3,400
	4	10 57 p.m.	Off the coast of Awa (Shikoku).	80	60	130	830	920	1,880
	16	3 19 a.m.	Nakano (Sagami).	70	40	—	100	1,550	1,650
	17	6 23 p.m.	Sea of Iyo.	60	30	—	150	1,180	1,330
	22	5 43 a.m.	Off Kinkazan (Rikuzen).	180	100	170	1,130	3,400	4,700
	23	11 30 p.m.	Sea of Aki.	60	50	210	740	1,240	2,190
	26	11 51 a.m.	Hachiman (Mino).	60	40	—	280	1,120	1,400
	28	8 18 p.m.	Off the coast of Tokachi.	250	100	—	200	1,850	2,050
Oct.	5	4 24 p.m.	Bay of Iburi.	170	90	—	1,200	3,900	5,100
	12	10 24 a.m.	Bay of Tôkyō.	70	40	—	430	1,200	1,630
	16	1 57 a.m.	Off the coast of Hitachi.	100	70	—	650	1,950	2,600
	25	9 33 a.m.	" Iwaki.	100	80	—	980	1,380	2,360
Nov.	5	5 49 p.m.	Vicinity of Tsukuba-San (Hitachi).	50	40	—	120	930	1,050
	6	11 17 a.m.	Vicinity of Etrup Island.	300	200	—	100	1,770	1,870

(1) Date.		(2) Time of occurrence		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1902					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Nov.	7	3^h58^m	p.m.	Off the coast of Iwaki.	70	60	—	340	1,380	1,720
	15	4 31	a.m.	Kanayama (Mino).	50	30	—	280	1,070	1,350
	,,	8 15	a.m.	Off Chōshi (Shimosa).	80	70	—	20	1,330	1,350
	20	8 35	a.m.	Off the coast of Iwaki.	120	90	260	990	2,550	3,800
	21	4 03	p.m.	Vicinity of Kōshun (Formosa).	200	100	200	800	1,300	2,300
Dec.	6	6 12	a.m.	Tainan (Formosa).	120	60	—	750	750	1,500
	,,	0 47	p.m.	Off the coast of Iwaki.	100	90	—	480	2,040	2,520
	,,	3 59	p.m.	Do.	90	70	—	150	1,170	1,320
	9	1 53	a.m.	Sugito (Musashi.)	80	40	60	900	1,340	2,300
	11	5 06	a.m.	Vicinity of Yaku-shima.	150	100	30	780	790	1,600
	14	1 57	p.m.	Mizukaido (Shimosa).	170	100	200	2,200	4,790	7,190
	17	9 49	a.m.	Off the coast of Iwaki.	100	80	120	230	2,000	2,350
	31	2 38	p.m.	Mizukaido (Shimosa). $\varphi = 35^\circ\ 59' N,\ \lambda = 139^\circ\ 55' E$	250	120	360	2,450	5,980	8,790
1903										
Jan.	2	5 27	p.m.	Off the coast of Iyo.	120	60	220	1,060	2,780	4,060
	5	8 44	a.m.	Shimosa.	70	30	—	210	1,190	1,400
	18	9 13	p.m.	Off the coast of Hidaka.	220	130	70	990	2,960	4,020
	30	1 44	p.m.	Do.	140	90	—	450	3,300	3,750
	31	1 47	a.m.	Off the SE. coast of Awa Peninsula.	250	180	—	300	8,200	8,500
Feb.	3	2 55	a.m.	Off the SE. coast of Nemuro.	250	100	—	150	1,370	1,520
	,,	4 59	a.m.	Vicinity of Saruhashi (Kai).	100	40	10	760	2,060	2,830
	,,	9 14	p.m.	Some distance off the coast of Iwaki.	350	200	100	2,450	9,350	11,900
	8	4 45	a.m.	Off the coast of Sendai.	180	90	130	810	5,160	6,100
	13	0 45	p.m.	,, Hitachi.	90	60	30	440	1,480	1,950
	14	4 48	p.m.	,, Iwaki.	130	60	70	680	1,960	2,710

(1) Date	(2) Time of occurrence	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shorter axis	(6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1903			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Feb. 18	11^h36^m a.m.	Off the coast of Iwaki.	90	60	—	200	1,950	2,150
20	7 30 p.m.	,, Mutsu.	130	90	—	290	1,030	1,320
23	11 44 p.m.	Vicinity of Ashio (Shimotsuke)	70	50	—	300	2,270	2,570
26	0 19 a.m.	Off the coast of Iwaki.	150	80	—	800	2,770	3,570
28	7 07 p.m.	,, Higo.	80	60	9	1,240	1,440	2,770
March 12	5 35 a.m.	Vicinity of Sekiyado (Shimosa).	90	40	—	380	2.010	2,390
,,	9 11 p.m.	Bungo Strait.	120	90	60	940	2,710	3,710
13	1 11 p.m.	Vicinity of Tochigi (Shimotsuke).	50	30	—	190	1,990	2,180
,,	3 04 p.m.	Vicinity of Kanagawa (Musashi).	110	50	—	300	2,630	2,930
21	7 36 p.m.	Off the coast of Suō.	270	150	1,210	4,610	6,640	12,460
,,	11 57 p.m.	Do.	80	50	—	430	2,070	2,500
22	6 12 a.m.	Do.	90	50	—	450	2,270	2.720
26	0 59 a.m.	,, Awa peninsula.	130	60	—	190	1,730	1,920
,,	8 21 a.m.	,, Rikuzen.	180	120	—	110	5,860	5,970
31	11 01 a.m.	Do.	200	100	—	450	4.320	4,770
April 1	11 09 p.m.	Do.	200	80	—	1,220	4,430	5,650
17	4 08 a.m.	,, E. coast of Nemuro.	120	60	230	450	680	1,360
19	7 48 p.m.	,, coast of Kazusa.	110	70	—	510	1,310	1,820
21	8 50 p.m.	Saruhashi (Kai).	90	40	10	450	2,050	2,510
22	5 02 a.m.	Boundary between Shimosa and Shimotsuke.	120	50	140	1.200	2,200	3,540
May 6	8 52 a.m.	Do.	80	40	—	230	1,440	1,670
10	3 19 a.m.	Off the coast of Iwaki.	170	110	270	1,400	2,880	4,550
June 2	7 59 p.m.	,, E. coast of Mutsu.	150	90	—	430	1.110	1,540

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1903					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
June	3	0^h28^m	p.m.	Vicinity of Hachijo-jima.	180	100	20	270	2,530	2,820
	7	8 38	a.m.	Boundary between Shimosa and Shimotsuke.	50	30	—	290	730	1,020
	,,	6 07	p.m.	Giran (Formosa).	350	?	850	1,400	150	2,400
July	1	9 10	a.m.	Off the coast of Hitachi.	300	180	660	3,270	6,630	10,560
	3	2 20	a.m.	,, Hyuga.	70	60	—	300	850	1,150
	6	3 19	a.m.	W. part of Hitachi.	80	60	—	680	1,710	2,390
	,,	1 59	p.m.	Sea of Ise.	220	120	500	3,050	5,360	8,910
	9	3 00	p.m.	N. part of Sagami.	90	50	40	390	2,660	3,090
	12	1 56	p.m.	Tainan (Formosa).	100	70	—	500	1,800	2,300
	15	4 51	a.m.	Sano (Shimotsuke).	70	40	–	230	2,430	2,660
	16	9 24	p.m.	Off the coast of Hyuga.	120	100	—	900	1,960	2,860
	17	10 50	a.m.	Central part of Kii.	100	60	130	400	1,070	1,600
	21	2 06	p.m.	Tochigi (Shimotsuke).	70	40	—	390	1,510	1,900
Aug.	10	1 40	p.m.	Hirayu, Yoshiki county, Hida.	100	50	40	530	3,300	3,870
	,,	1 46	p.m.	Do.	90	50	30	300	2,940	3,270
	14	0 47	a.m.	Off the coast of Nemuro.	400	200	170	810	2,690	3,670
	,,	1 08	a.m.	Do.	400	100	—	290	1,480	1,770
	,,	10 16	a.m.	Do.	350	100	—	350	2,300	2,650
	23	9 33	p.m.	Uraga Channel.	150	80	—	240	2,240	2,480
	31	1 24	p.m.	Off the coast of Iwaki.	130	70	30	290	2,020	2,340
Sept.	3	1 26	a.m.	,, Rikuzen.	120	60	—	470	1,790	2,260
	5	2 38	a.m.	Central part of Rikuchu.	60	30	—	380	630	1,010
	7	4 14	p.m.	Off the coast of Taito (Formosa).	120	70	—	300	1,700	2,000
	10	1 26	p.m.	,, Formosa.	80	50	—	480	610	1,090

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) Longer axis	(5) Shorter axis	(6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1903					ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Sept.	10	$5^h 45^m$	p.m.	Taito (Formosa).	80	70	100	400	1,700	2,200
	18	7 44	p.m.	Off the coast of Hidaka.	230	140	20	920	4,410	5,350
	20	9 12	p.m.	,, Iwaki.	130	90	—	360	3,320	3,680
	21	7 33	p.m.	,, Rikuchu.	100	60	—	230	840	1,070
Oct.	11	1 41	a.m.	,, Hyuga.	140	100	470	1,160	1,660	3,290
	12	9 51	p.m.	,, Hidaka.	120	70	—	220	1,900	2,120
	27	9 57	p.m.	Tokyo Bay.	160	[illegible]	330	2,550	3,060	5,940
Nov.	1	6 35	a.m.	Taichu (Formosa).	70	50	—	150	970	1,120
	6	7 04	p.m.	Off Yokosuka in Tokyo Bay.	80	50	—	70	1,150	1,220
	10	5 51	p.m.	Tokyo Bay.	160	90	170	1,710	3,200	5,080
	20	4 17	p.m.	Off the coast of Iwaki.	190	140	920	2,490	4,250	7,660
	29	7 11	p.m.	Do.	80	50	50	340	1,180	1,570
Dec.	1	11 21	p.m.	Taichu (Formosa).	100	60	—	200	2,080	2,280
	3	5 52	p.m.	Off the coast of Osumi.	130	90	100	750	930	1,780
	9	8 55	a.m.	N. part of Shimosa.	35	30	—	140	1,150	1,290
	18	11 20	a.m.	Off the coast of Hitachi.	200	120	890	2,530	3,680	7,100
	28	11 25	p.m.	,, Kinkazan (Rikuzen).	180	100	—	620	3,880	4,550
	31	2 10	p.m.	Sea of Aki.	80	30	90	270	2,170	2,530
1904										
Jan.	19	5 47	a.m.	Off the E. coast of Rikuzen.	80	60	—	230	1,010	1,240
	,,	4 09	p.m.	,, Iwaki.	90	60	—	60	1,500	1,560
Feb.	24	8 32	p.m.	Off Kinkazan (Rikuzen).	180	100	10	1,850	3,570	5,430
	26	5 50	p.m.	Tokyo Bay.	80	70	40	790	2,020	2,850

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shroter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1904			*ri*	*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*
March 7	7^h37^m a.m.	S. part of Yamato.	50	40	100	270	180	550
8	3 40 a.m.	Off the coast of Hitachi.	220	120	490	2,010	4,200	6,700
„	11 29 p.m.	Do.	70	60	—	230	1,020	1,250
12	6 12 a.m.	Vicinity of Kasumiga-ura.	100	60	—	200	900	1,100
18	5 33 a.m.	Off the W. coast of Kii.	130	90	290	1,120	3,220	4,630
„	10 44 p.m.	„ SE. coast of Nemuro.	400	200	870	2,850	7,500	11,220
25	2 56 a.m.	„ E. coast of Rikuzen.	120	50	—	180	1,040	1,220
26	8 20 a.m.	SW. part of Ise.	40	25	—	310	420	730
27	1 32 p.m.	Off the E. coast of Mutsu.	110	70	—	240	1,330	1,570
28	6 28 p.m.	Boundary between Iwaki and Rikuzen.	40	30	—	210	290	500
April 4	8 20 a.m.	Vicinity of Kasumiga-ura.	70	60	—	170	1,620	1,790
13	2 38 p.m.	Off the coast of Rikuzen.	160	60	—	380	4,250	4,550
18	7 51 p.m.	Do.	60	50	—	30	590	620
„	8 03 p.m.	Uraga channel.	80	70	—	640	2,540	3,180
19	1 21 p.m.	Off the coast of Kushiro.	250	160	—	100	1,420	1,520
23	4 51 a.m.	Off the E. coast of Rikuzen.	180	80	—	1,870	4,740	6,610
24	8 08 a.m.	Outside the Rikuzen Bay.	270	140	750	2,280	3,930	6,960
„	3 38 p.m.	Toroku, Kagi, Ensuiko, Tainan, and Banshoryo (Formosa) $\varphi = 23^\circ\ 30'$N, $\lambda = 120^\circ\ 26'$E	160	80	360	1,270	630	2,260
27	3 14 a.m.	Vicinity of Tsukuba-San.	40	30	—	160	610	770
May 8	4 23 a.m.	Muikamachi (Echigo). $\varphi = 36^\circ\ 53'$N, $\lambda = 138^\circ\ 48'$E	230	140	1,080	4,770	5,860	11,710
„	7 24 a.m.	Sahara (Shimosa).	60	40	—	60	1,310	1,370
„	8 00 a.m.	Muikamachi (Echigo).	80	50	—	400	2,360	2,760
16	2 24 p.m.	N. part of Suruga.	60	50	—	700	1 050	1,750
17	4 03 p.m.	Bay of Chiba (Tokyo Bay).	80	50	—	170	1,750	1,920
20	5 35 p.m.	Sea of Aki.	220	180	760	3,030	6,480	10,270

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1904				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
May	21	5h25m a.m.	Off the E. coast of Mutsu.	120	100	—	430	1,920	2,350
	23	3 31 a.m.	,, coast of Harima.	110	90	330	960	4,130	5,420
	27	5 41 a.m.	Uraga channel.	70	60	—	140	1,310	1,45.
	,,	7 46 a.m.	Tokyo Bay.	50	40	—	70	880	950
June	6	3 41 a.m.	Vicinity of Shishido Lake, Izumo.	150	130	570	1,890	4,030	6,490
	,,	11 51 a.m.	Do.	180	100	460	2,370	6,290	9,120
	7	5 19 p.m.	Off the coast of Iwaki. $\varphi=38°N, \lambda=144° 15'E$.	450	300	90	5,850	14,650	20,590
	14	10 39 a.m.	Off the coast of Rikuzen.	150	130	—	310	5,570	5,880
	15	2 17 a.m.	S. part of Rikuzen.	70	40	—	120	850	970
	22	11 26 a.m.	Off Kinkazan (Rikuzen).	140	80	10	510	2,770	3,290
	24	3 44 a.m.	Vicinity of Lake Suwa (Shinano).	70	35	—	270	1,050	1,320
	30	8 21 a.m.	Sahara (Shimosa).	70	35	60	320	790	1,170
	,,	8 22 a.m.	Do.	40	30	40	250	370	660
July	1	10 29 p.m.	Off the SE. coast of Nemuro.	350	300	250	2,300	5,250	7,800
	8	0 02 p.m.	Neo-Valley (Mino).	40	20	—	130	390	520
	12	7 40 p.m.	Off the E. coast of Kazusa.	200	180	—	160	5,440	5,600
	13	4 13 p.m.	,, Mutsu.	180	150	—	920	2,330	3,250
	15	3 44 a.m.	,, Kazusa.	130	80	—	460	1,630	2 090
	,,	3 53 a.m.	Do.	70	40	—	170	420	590
	16	10 09 a.m.	Do.	200	150	180	830	4,300	5,310
	,,	10 34 a.m.	Do.	70	40	—	310	620	930
	17	4 27 a.m.	Do.	100	60	—	960	1,360	2 320
	18	7 51 p.m.	Do.	80	60	40	250	1,170	1,460
	19	6 20 p.m.	Do.	140	70	80	270	2,250	2,600
	20	0 30 p.m.	Do.	140	130	70	550	4,530	5,150

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1904				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
July	26	9^h01^m p.m.	Bay of Iburi.	150	70	—	420	2,590	3,010
Aug.	4	9 49 p.m.	N. part of Shimosa. $\varphi=35°\ 43'\ N, \lambda=139°54'\ E.$	150	90	320	1,250	1,840	3,410
	7	5 25 a.m.	Outside the Rikuzen Bay.	210	50	10	690	3,000	3,700
	15	10 30 p.m.	,,	160	80	210	1,050	1,560	2,820
	21	6 49 a.m.	Off the E. coast of Kunajiri-shima.	250	200	—	100	800	900
	22	10 03 p.m.	Off the SE. coast of Nemuro.	350	200	—	1,160	2,380	3,540
	25	6 01 a.m.	Off the Island of Oshima. (Lyu Kyu)	400	250	20	1,340	2,910	4,270
	26	9 22 a.m.	Tsugaru Strait.	120	80	—	90	340	430
	29	2 39 p.m.	Vicinity of Kameyama (Tanba).	70	40	—	360	730	1,090
Sept.	4	9 53 p.m.	Central part of Kii.	35	25	—	210	410	620
	7	1 50 p.m.	Taichu (Formosa).	130	80	—	260	740	1,000
	14	2 59 a.m.	Off the coast of Tokachi.	100	70	—	150	960	1,110
	20	4 18 a.m.	Bay of Chichiiwa (Hizen).	50	30	—	90	180	270
	21	2 51 p.m.	Off the coast of Iyo.	180	130	760	3,260	2,650	6,670
	25	10 35 a.m.	Tsugaru strait.	180	100	—	810	2,350	3,160
Oct.	5	0 35 a.m.	N. part of Shimosa.	70	30	—	130	1,700	1,830
	7	11 12 a.m.	Off the E. coast of Kii.	60	30	60	350	660	1,070
	13	7 23 p.m.	,, coast of Iwaki.	60	30	—	160	1,350	1,510
	20	2 01 a.m.	S. part of Mikawa.	70	50	—	380	560	940
	,,	6 28 p.m.	Off the coast of Hidaka.	220	100	—	490	2,120	2,610
	25	0 28 a.m.	,, Iwaki.	180	70	110	430	1,840	3,380
	27	6 24 a.m.	,, Shimosa.	90	70	—	90	380	470
	28	7 11 a.m.	,, Hitachi.	180	150	—	120	5,220	5,340

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1904			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Nov. 3	5h46m p.m.	Outside the Rikuzen Bay.	110	70	—	210	900	1,110
4	1 45 p.m.	Off Kinkazan (Rikuzen).	120	80	10	200	430	6,400
6	6 25 a.m.	Kagi, Toroku, and Ensuiko (Formosa). $\varphi = 23°30'$N, $\lambda = 120°26'$E.	?	?	520	800	790	2,110
7	4 20 p.m.	Boundary between Mikawa and Mino.	60	40	—	170	460	630
11	0 10 a.m.	Kashiwabara (Tango).	50	40	—	160	730	890
13	9 49 a.m.	Vicinity of Ogasawara-jima.	—	—	—	10	580	590
Dec. 16	5 23 p.m.	Off the coast of Shimosa.	80	50	—	100	210	340
17	9 40 a.m.	Do.	140	80	—	210	1,070	1,280
,,	4 03 p.m.	Off the E. coast of Mutsu.	250	150	530	3,790	3,060	6,850
22	7 39 p.m.	Vicinity of Kumamoto (Higo).	70	60	60	580	810	1,450
23	9 56 a.m.	Off the coast of Shimosa.	130	90	—	230	400	630
24	11 47 a.m.	,, Rikuzen.	280	160	640	2,280	2,950	5,870
1905								
Jan. 2	4 26 p.m.	N. part of Rikuzen.	80	50	—	80	1,340	1,420
,,	11 55 p.m.	Off the coast of Taito (Formosa).	160	120	—	240	660	900
11	7 15 a.m.	S. part of Formosa.	90	?	—	360	340	700
23	8 31 a.m.	Off the W. coast of Sado.	70	60	—	50	730	780
25	11 12 a.m.	Boundary between Chikugo and Higo.	60	50	110	380	1,490	1,980
26	4 02 p.m.	Off the coast of Hitachi.	100	70	—	510	1,550	2,060
28	9 57 p.m.	S. part of Hyuga.	70	50	110	490	730	1,330
Feb. 2	8 15 a.m.	Off Cape Erimo (Hidaka).	230	120	—	270	850	1,120
,,	9 08 a.m.	Outside the Rikuzen Bay.	90	50	—	10	340	350
5	3 41 a.m.	Vicinity of Lake Biwa.	?	130	490	2,470	1,740	4,700
7	11 28 a.m.	Outside the Rikuzen Bay.	80	50	—	70	230	300

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shorter axis	(6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1905			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Feb. 7	0^h33^m p.m.	SE. part of Mino.	60	25	—	120	280	400
„	2 47 p.m.	Off the coast of Iwaki.	130	70	—	140	990	1,130
11	7 06 a.m.	Do.	90	60	—	60	760	820
14	10 55 p.m.	Do.	110	60	—	40	930	970
17	3 27 a.m.	Outside the Rikuzen Bay.	120	50	—	10	1,080	1,090
„	6 44 p.m.	Off the coast of Iwaki.	130	80	190	660	1,160	2,010
21	2 24 p.m.	„ Cape Erimo (Hidaka).	280	150	—	500	3,150	3,650
26	8 45 p.m.	„ the E coast of Mutsu.	200	120	—	510	1,390	1,900
27	1 19 a.m.	Off Chôshi (Shimosa).	80	40	—	30	260	290
28	11 01 p.m.	Bay of Wakasa.	90	60	—	230	880	1,110
March 4	9 18 p.m.	Bay of Chiba (Tokyo Bay).	110	60	—	400	720	1,120
6	6 08 a.m.	Uraga Channel.	70	40	—	210	800	1,010
„	10 32 a.m.	Off the coast of Rikuzen.	110	70	—	140	360	500
13	0 46 p.m.	„ Hyuga.	80	60	—	30	440	470
16	11 54 p.m.	Bungo Strait.	120	60	40	540	940	1,520
18	4 40 a.m.	Bay of Toyama (Etchu).	130	100	20	860	1,180	2,060
April 6	11 10 a.m.	Off the SE. coast of Kunashiri.	150	80	10	200	680	890
„	9 30 p.m.	E. part of Musashi.	80	50	—	940	1,770	2,710
10	10 04 p.m.	Off the coast of Taitô (Formosa).	100	80	—	650	1,500	2,150
13	6 02 p.m.	Vicinity of Yokohama.	140	60	150	420	470	1,040
16	8 05 a.m.	Off Cape Shiriya (Mutsu).	150	120	190	850	1,000	2,040
18	0 21 a.m.	Sea of Aki.	60	20	50	260	830	1,140
21	5 15 a.m.	S. part of Musashi.	130	60	—	770	790	1,560
May 9	2 54 a.m.	Off the coast of Hitachi.	200	140	—	170	1,200	1,370

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1905					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
May	17	2h04m	a.m.	Off the coast of Hidaka.	180	100	190	770	1,090	2,050
	26	3 46	p.m.	" Iwaki.	150	70	70	310	1,450	1,830
	30	4 32	a.m.	Kanagawa (Musashi).	60	20	—	40	90	130
	31	11 08	a.m.	Off the coast of Hidaka.	120	60	—	130	430	560
June	2	2 40	p.m.	Central part of Inland Sea.	450	200	4,750	3,950	2 200	10,900
	"	7 56	p.m.	Do.	230	140	120	3,390	4,960	8,470
	3	9 18	a.m.	Do.	110	60	—	970	3,990	4.960
	"	9 34	a.m.	Do.	180	90	280	2,870	3,200	6,350
	"	7 24	p.m.	Do.	100	50	—	1,040	2,990	4,030
	"	7 38	p.m.	Do.	180	70	200	1,800	2,500	4,500
	"	10 49	p.m.	Do.	120	60	—	860	2.490	3,350
	4	3 08	a.m.	Do.	90	50	—	590	1,720	2,310
	5	8 44	a.m.	Vicinity of O-shima (Izu).	60	50	10	150	200	360
	6	0 44	a.m.	Do.	90	70	—	190	420	610
	"	1 19	a.m.	Do.	60	40	—	380	260	640
	"	1 51	a.m.	Do.	100	70	—	460	430	890
	"	2 05	a.m.	Do.	70	60	—	510	210	720
	"	2 23	a.m.	Do.	90	70	—	580	230	810
	"	5 17	a.m.	Do.	90	60	—	320	100	420
	"	9 23	a.m.	Do.	90	60	—	300	230	530
	"	11 47	a.m.	Do.	60	40	—	160	170	330
	"	8 32	p.m.	Central part of Inland Sea.	80	40	—	570	1,230	1,800
	7	6 12	a.m.	Vicinity of Edosaki (Hitachi)	40	30	—	70	690	760
	"	2 40	p.m.	Vicinity of O-shima (Izu).	220	120	510	740	2,220	3,470
	"	10 06	p.m.	Do.	110	70	150	280	390	820
	10	3 10	p.m.	Do.	150	100	—	270	440	710

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) *Longer axis*	(5) *Shorter axis*	(6) *Strong motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1905				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
June	11	11ʰ52ᵐ p.m.	N. part of Shimosa.	70	40	—	380	540	920
	12	5 17 p.m.	Off the coast of Iwaki.	250	130	750	1,620	2,450	4,820
	13	2 49 p.m.	Off Kinkazan (Rikuzen).	80	70	—	510	730	1,240
	18	1 17 a.m.	Off the coast of Iwaki.	140	100	—	210	1,620	1,830
	20	0 36 p.m.	„ Nemuro.	300	100	—	110	1,420	1,530
	21	6 45 p.m.	N. part of Mino.	90	40	—	370	1,220	1,590
	27	1 13 a.m.	Central part of Rikuchū.	220	70	—	1,890	1,130	3,020
July	1	1 49 a.m.	Vicinity of Mishima (Nagato).	90	50	—	220	600	820
	„	9 06 a.m.	Ayabe (Tanba).	60	50	20	600	630	1,250
	7	1 22 a.m.	Off the coast of Iwaki.	300	200	1,400	4,380	2,280	8,060
	„	7 18 a.m.	Do.	300	180	—	440	4,840	5,280
	„	10 19 a.m.	Off the coast of Tokachi.	240	160	—	140	4,700	4,840
	9	7 13 a.m.	„ Iwaki.	230	140	30	1,670	2,930	4,630
	13	1 49 p.m.	„ E. coast of Mutsu.	270	150	—	420	3,180	3,600
	16	6 49 p.m.	„ coast of Ugo.	120	100	—	400	1,130	1,530
	19	5 03 p.m.	Bay of Tokyo.	80	50	—	60	560	620
	21	6 16 p.m.	Off Kinkazan (Rikuzen).	110	80	—	510	570	1,080
	23	5 26 p.m.	Town of Yasuzuka, Higashi-Kubiki county (Echigo).	140	100	110	770	2,330	3,210
	„	6 27 p.m.	Do.	110	60	10	100	830	940
	„	7 01 p.m.	Off Kinkazan (Rikuzen).	150	80	—	170	1,370	1,540
	27	1 39 a.m.	S. part of Shimotsuke.	90	40	—	140	1,150	1,290
Aug.	5	2 29 p.m.	SE. part of Hida.	90	40	—	290	610	900
	12	9 28 p.m.	Bay of Tokyo.	60	30	—	70	400	470
	18	6 08 a.m.	Bay of Atsumi (Mikawa).	90	40	—	270	350	620
	22	11 32 p.m.	Off the E. coast of Rikuzen.	110	60	—	260	440	700

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) *Longer axis*	(5) *Shorter axis*	(6) *Strong motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1905			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Aug. 24	0^h05^m p.m.	Off the coast of Hitachi.	100	50	—	490	940	1,430
,,	6 11 p.m.	Hagiwara, Masuda county (Hida).	110	40	40	230	500	770
26	5 16 p.m.	Off Cape Muroto (Tosa).	140	70	160	880	1,400	2,440
29	1 28 p.m.	Off the SE. coast of Kushiro.	250	150	—	400	670	1,070
30	9 27 a.m.	,, Omae-zaki (Totomi).	90	50	—	60	620	680
Sept. 1	11 47 a.m.	Off the E. coast of Mutsu.	300	200	240	3,720	2,240	6,200
,,	2 52 p.m.	,, coast of Totomi.	60	50	—	260	180	440
2	0 52 a.m.	Tono-machi (Rikuchu).	150	70	—	530	820	1,350
,,	3 48 p.m.	Off the coast of Rikuzen.	200	100	—	440	870	1,290
3	2 02 a.m.	Uraga channel.	120	70	160	550	1,240	1,950
6	5 11 p.m.	Off the E. coast of Kii.	70	45	80	290	210	580
8	11 06 a.m.	Boundary between Hōki and Izumo.	40	25	—	170	330	500
9	3 01 p.m.	S. part of Kii.	80	50	110	490	250	850
12	0 52 p.m.	Central part of Inland Sea.	170	90	470	3,180	2,500	6,150
21	10 00 p.m.	Vicinity of Chiba (Shimosa).	150	110	—	980	1,420	2,400
24	2 08 a.m.	Boundary between Hitachi and Shimosa.	70	40	—	180	480	660
29	10 19 a.m.	Boundary between Mino and Echizen.	140	80	—	1,100	1,850	2,950
30	11 31 p.m.	Off the E. coast of Mutsu.	120	70	—	50	1,000	1,050
Oct. 2	10 54 a.m.	Off the coast of Hitachi.	200	150	120	2,830	2,080	5,030
3	6 18 p.m.	Boundary between Hida and Kaga.	110	40	—	160	600	760
4	8 15 a.m.	Off Cape Shiriya (Mutsu).	270	180	350	3,950	2,700	7,000
7	9 53 p.m.	Off the E. coast of Mutsu.	120	90	—	180	640	820
10	10 54 a.m.	Off Chōshi (Shimosa).	170	140	—	660	1,100	1,760
13	3 14 p.m.	Off Cape Kamui (Shiribeshi).	120	100	50	490	990	1,530
14	11 54 a.m.	Bay of Chiba (Tokyo Bay).	160	60	40	560	850	1,450

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1905				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Oct.	16	1ʰ52ᵐ a.m.	SE. part of Hida.	90	50	—	200	1,210	1,410
	19	1 42 a.m.	Central part of Mino.	80	50	—	290	449	730
	„	9 10 a.m.	E. part of Musashi.	130	50	—	470	930	1,400
	24	0 48 p.m.	Off the E. coast of Awa peninsula.	220	120	—	250	1,020	1,270
	28	6 45 p.m.	Off the SE. coast of Kushiro.	250	100	—	300	550	850
Nov.	1	2 00 p.m.	Off the coast of Iwaki.	140	80	—	360	1,530	1,890
	2	11 21 a.m.	„ Kazusa.	160	120	—	620	1,260	1,880
	9	7 19 p.m.	W. part of Echigo.	140	120	—	710	1,150	1,860
	22	9 43 a.m.	Off the E. coast of Formosa.	100	?	—	1,660	780	2,440
	23	0 01 a.m.	Off the coast of Rikuchû.	200	100	—	460	830	1,290
Dec.	2	6 32 a.m.	Ariake Sea (Higo).	200	150	110	1,180	750	2,040
	3	1 46 p.m.	Off Kinkazan (Rikuzen).	180	130	10	1,110	2,260	3,380
	5	1 18 a.m.	Do.	150	80	10	270	900	1,180
	„	4 38 a.m.	Outside the Iburi Bay.	160	80	—	80	800	880
	8	0 08 p.m.	Central part of Inland Sea.	240	160	770	4,130	3,340	8,240
	„	1 26 p.m.	Do.	220	160	380	4,850	3,390	8,620
	17	6 29 p.m.	Off the coast of Nagato.	80	70	—	120	1,590	1,710
	23	11 37 a.m.	„ Rikuchû.	250	170	760	2,310	2,360	5,430
	26	0 11 p.m.	Off the coast of Hitachi.	220	160	920	2,680	2,220	5,820
	27	0 51 p.m.	Kaita-mura, Nishi-Chikuma county, Shinano.	160	50	20	400	1,140	1,560
	30	7 53 p.m.	Bay of Chiba (Tokyo Bay).	50	40	—	70	200	270
1906									
Jan.	1	6 18 a.m.	Sea of Ise.	80	50	—	730	710	1,440
	5	6 06 a.m.	Bay of Osaka.	30	20	—	120	440	560
	„	6 01 p.m.	Do.	40	30	—	400	500	900

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1906			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Jan. 6	$4^h 28^m$ a.m.	Off the E. coast of Mutsu.	110	90	—	530	860	1,390
,,	0 48 p.m.	,, Rikuchu.	70	50	—	260	310	570
7	8 52 p.m.	Bay of Osaka.	90	60	—	700	810	1,510
8	11 00 p.m.	Off the coast of Sagami.	180	120	20	830	840	1,690
9	6 50 p.m.	Central part of Shimosa.	70	40	—	220	690	910
,,	9 55 p.m.	Bay of Chiba (Tokyo Bay).	60	40	—	20	320	340
12	10 23 a.m.	Off the E. coast of Kii.	130	90	200	900	790	1,890
15	7 54 a.m.	N. part of Sagami.	40	30	—	100	340	440
18	9 20 p.m.	N. part of Mino.	140	80	170	1,420	1,640	3,230
21	10 50 p.m.	Off the E. coast of Main Island $\varphi = 34° 23' \text{N}, \lambda = 143° 26' \text{E}.$	400	350	1,640	5,260	7,570	14,470
24	5 07 a.m.	Off the coast of Iwami.	150	50	—	280	1,110	1,390
Feb. 4	3 24 p.m.	Rikuzen Bay.	220	130	90	2,150	2,230	4,470
5	3 11 a.m.	Outside the Rikuzen Bay.	150	60	—	240	1,030	1,270
,,	5 09 a.m.	Rikuzen Bay.	200	120	—	880	2,200	3,080
17	6 41 a.m.	Off the E. coast of Kazusa.	340	140	50	400	530	980
18	2 15 p.m.	S. part of Kazusa.	140	110	—	270	690	960
23	6 49 p.m.	Off the coast of Awa and Kazusa peninsula.	300	200	290	1,900	3,500	5,690
24	9 14 a.m.	Tokyo Bay.	350	200	840	4,190	5,070	10,100
28	0 10 a.m.	S. part of Ise.	70	40	—	230	700	930
March 6	1 38 a.m.	Off the coast of Awa and Kazusa.	250	200	—	120	190	310
7	11 17 a.m.	Off the coast of Iwaki.	250	150	—	380	2,980	3,360
8	4 08 a.m.	Boundary between Mino and Owari.	90	60	—	190	740	930
13	10 29 p.m.	Off the coast of Hyūga.	200	150	910	2,160	2,700	5,770
14	1 11 a.m.	Do.	70	60	—	40	80	120
,,	8 32 p.m.	Off the coast of Kazusa.	100	80	—	450	1,080	1,530

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) *Longer axis*	(5) *Shorter axis*	(6) *Strong motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1906			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
March 16	0^h05^m a.m.	Central part of Inland Sea.	100	50	—	100	3,100	3,200
17	8 43 a.m.	Kagi (Formosa).	500	?	970	1,310	—	2,280
,,	9 21 p.m.	Northern part of Ariake Sea, (Kyushu).	40	30	—	90	810	900
,,	9 23 p.m.	Do.	200	120	250	2,150	1,200	3,600
18	0 12 a.m.	Do.	60	30	—	80	230	310
,,	1 10 a.m.	S. part of Kii.	170	110	160	1,080	2,330	3,570
,,	5 32 a.m.	Northern part of Ariake Sea (Kyushu).	40	20	—	60	630	690
,,	6 30 a.m.	Off the coast of Hyûga.	150	100	—	150	2,290	2,440
21	11 43 p.m.	,, Rikuzen.	170	100	—	190	790	980
23	5 40 a.m.	,, E. coast of Mutsu.	200	150	—	210	560	770
24	9 59 a.m.	Near O-shima (Lyu-kyu).	150	—	—	80	20	100
26	1 29 p.m.	Kagi (Formosa).	100	80	200	1,090	940	2,230
28	8 57 a.m.	Do.	80	70	100	520	1,580	2,200
29	6 14 a.m.	Do.	100	80	200	920	420	1,540
April 4	10 04 a.m.	Off the coast of Rikuzen.	130	70	—	340	820	1,160
5	11 50 a.m.	,, Iwaki.	240	180	190	2,370	3,090	5,650
6	4 58 a.m.	Kagi (Formosa).	100	80	70	650	940	1,660
,,	7 29 p.m.	Off the E. coast of Nemuro.	350	?	20	400	470	890
7	2 52.7 p.m.	Tenshiko (Formosa).	—	160	270	970	970	2,210
8	8 39.7 a.m.	Kagi ,,	100	80	100	920	1,120	2,140
,,	2 52 p.m.	Off the E. coast of Awa peninsula.	160	70	—	680	1,620	2,300
9	2 38 a.m.	Off the coast of Iwaki.	230	160	—	360	3,890	4,250
11	7 08 p.m.	NW. part of Mino.	140	90	90	1,530	1,770	3,390
14	5 18 a.m.	Tenshiko (Kagi Prefecture) Formosa.	—	—	2,060	220	—	2,280
,,	9 52 a.m.	Do.	—	—	740	1,240	300	2,280
20	9 48 p.m.	Hagiwara, Masuda county (Hida).	90	70	60	310	1,850	2,220

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) Longer axis	(5) Shorter axis	(6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1906					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
April	21	4h 40m	a.m.	Hagiwara, Masuda county (Hida).	?	210	580	3,320	3,310	7,210
	,,	3 54	p.m.	Kosaka, Masuda county (Hida).	110	60	40	210	820	1,070
May	1	7 12	p.m.	Bungo Strait.	80	60	—	290	1,360	1,650
	2	11 13	a.m.	Off the N. coast of Formosa.	150	?	—	450	2,000	2,450
	5	8 09	a.m.	,, S. coast of Kii.	450	200	1,160	2,160	6,330	9,650
	,,	8 53	a.m.	Central part of Kii.	90	60	100	700	1,030	1,830
	6	10 20	p.m.	NW. part of Higo.	60	35	10	170	470	650
	7	8 01	a.m.	Off the E. coast of Awa peninsula.	120	70	—	120	410	530
	10	2 34	p.m.	Vicinity of Kawawa (Musashi).	80	40	—	40	250	290
	16	7 10	p.m.	Off the coast of Hitachi.	170	140	—	30	1,700	1,730
	18	4 04	p.m.	,, Iwaki.	120	90	—	390	1,600	1,990
	,,	9 36	p.m.	,, Shimosa.	110	70	—	40	230	270
	19	1 31	a.m.	Do.	220	180	170	670	2,980	3,820
	21	2 21	p.m.	Tokyo Bay.	120	60	—	380	430	810
	,,	3 56	p.m.	N. part of Shimosa.	150	80	250	1,710	1,430	3,390
	22	4 12	p.m.	Central part of Inland Sea.	150	120	650	1,570	2,220	4,440
	24	2 17	p.m.	Uraga channel.	45	30	—	60	210	270
	28	4 10	a.m.	Off the E. coast of Nemuro.	300	200	60	580	1,300	1,940
	,,	6 59	a.m.	,, coast of Kazusa.	140	90	—	350	470	820
	29	11 22	p.m.	N. part of Shimosa.	130	70	120	1,080	1,060	2,260
	30	9 27	p.m.	Tokyo Bay.	60	35	—	190	500	690
June	2	7 18	a.m.	Vicinity of Naruto, Awa.	80	60	170	850	890	1,910
	10	10 37	a.m.	Off Kinkazan (Rikuzen).	80	60	—	10	320	330
	22	2 28	a.m.	Uyeda (Shinano).	60	50	40	400	560	1,000
July	7	7 30	p.m.	Outside the Rikuzen Bay.	180	90	—	170	1,490	1,660

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1906			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
July 7	8h41m p.m	Off Kinkazan (Rikuzen).	130	70	—	90	310	400
10	9 37 a.m.	Off the coast of Iwaki.	90	70	—	120	330	450
11	5 32 a.m.	Central part of Mikawa.	50	30	—	100	610	710
12	4 31 p.m.	Off the coast of Hitachi.	160	100	—	170	640	810
23	1 18 p.m.	" Iwaki.	180	140	280	1,880	2,770	4,930
31	8 58 p.m.	" Rikuchū.	90	70	—	160	520	680
Aug. 5	4 53 a.m.	Tokyo Bay.	70	60	—	440	770	1,210
"	5 32 a.m.	Do.	120	50	210	860	1,350	2,420
9	9 15 p.m.	Off the coast of Hyuga.	130	80	—	140	450	590
"	10 27 p.m.	Do.	200	100	—	1,050	1,030	2,080
16	6 26 a.m.	Central part of Izu.	90	70	—	190	430	620
"	3 39 p.m.	Do.	100	80	50	80	930	1,060
19	8 00 a.m.	Off Chōshi (Shimosa).	180	120	10	730	2,940	3,680
21	5 42 a.m.	W. part of Kazusa.	140	50	—	80	290	370
22	0 08 a.m.	W. part of Shimosa.	120	50	100	810	920	1,830
31	11 20 a.m.	Central part of Izu.	140	80	10	350	920	1,280
Sept. 4	9 46 a.m.	Town of Mifune, (Higo).	60	45	—	160	110	270
8	3 53 a.m.	Off the E coast of Awa and Kazusa.	170	90	—	130	770	900
15	0 34 a.m.	Vicinity of Matsuzaka (Ise).	60	30	—	50	100	150
17	5 27 p.m.	W. part of Hitachi.	130	110	—	680	1,940	2,620
19	7 55 p.m.	Central part of Izu.	60	40	—	60	490	550
Oct. 4	0 05 a.m.	Off the coast of Rikuzen.	120	60	—	230	370	600
6	6 35 p.m.	N. part of Shimosa.	120	50	—	550	1,700	2,250
"	8 52 p.m.	Near the coast of Iwaki.	150	100	—	1 210	2,210	3,420

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1906				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Oct.	6	9h24m p.m.	Central part of Shimotsuke.	110	50	—	120	1,610	1,730
	10	9 51 p.m.	SW. part of Iwaki.	140	80	—	1,200	1,650	2,850
	12	9 56 a.m.	Off the coast of Ugo.	180	140	200	2,180	1,810	4,190
	,,	10 04 a.m.	Do.	220	140	590	1,570	1,950	4,110
	19	9 29 p.m.	Off the coast of Awa and Kazusa.	100	70	—	160	360	520
	,,	10 46 p.m.	Bungo Strait.	70	40	—	530	1,040	1,570
	23	7 13 a.m.	N. shore of Lake Biwa.	35	30	—	140	290	430
	26	5 25 p.m.	S. part of Yamato.	90	50	—	380	340	720
	27	7 25 a.m.	Off the coast of Iwaki.	300	200	—	320	3,550	3,870
Nov.	7	11 54 p.m.	,, Sagami.	70	50	—	150	350	500
	9	6 54 p.m.	,, Iwaki.	120	50	—	140	540	680
	11	0 33 a.m.	,, Awa peninsula.	50	30	—	20	80	100
	12	11 07 p.m.	Vicinity of Kasumiga-ura.	150	80	60	1,370	1,610	3,040
	15	7 24 p.m.	N. part of Hyuga.	50	40	—	360	520	880
	16	1 54 a.m.	W. part of Owari.	40	20	—	90	140	230
	22	6 44 a.m.	Central part of Bingo.	50	30	—	140	490	630
	23	3 32 p.m.	Off the coast of the Awa peninsula.	180	100	30	670	630	1,330
	24	4 40 a.m.	Off Kinkazan (Rikuzen).	110	60	—	10	570	580
	,,	5 45 p.m.	Do.	90	60	—	10	580	590
Dec.	2	0 33 p.m.	Vicinity of Ueda (Shinano).	60	30	—	100	230	330
	4	8 44 p.m.	Off the coast of Hitachi.	90	50	—	160	830	990
	5	5 54 p.m.	Central part of Kii.	50	40	—	330	330	660
	10	7 52 a.m.	Tosa Bay.	100	80	20	230	820	1,070
	24	5 46 p.m.	Katori county (Shimosa).	80	60	—	90	250	340
	27	9 05 p.m.	Vicinity of Ueda (Shinano).	70	30	—	80	180	260

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) *Longer axis*	(5) *Shorter axis*	(6) *Strong motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1907					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Jan.	3	3^h42^m	a.m.	N. part of Shimosa.	150	80	110	900	1,300	2,310
	5	1 47	a.m.	Off Cape Erimo (Hokkaido).	300	150	—	420	3,810	4,230
	10	0 48	p.m.	Do.	270	160	—	690	2,130	2,820
	18	8 23	p.m.	Off the W. coast of Kii.	80	70	—	410	1,210	1,620
	21	9 22	p.m.	Off Cape Erimo (Hokkaido).	300	150	—	120	3,670	3,790
	25	0 33	a.m.	Off the E. coast of Kazusa.	130	110	—	410	620	1,030
	„	6 35	p.m.	„ coast of Hitachi.	85	60	—	140	680	820
Feb.	6	5 38	p.m.	Some distance off the E. coast of Awa-Kazusa peninsula.	400	200	10	110	3,130	3,250
	12	1 26	a.m.	Tsugaru Strait.	200	100	—	170	400	570
	„	7 39	a.m.	Rikuzen Bay.	160	130	—	450	1,810	2,260
	20	9 52	p.m.	Off the coast of Rikuzen.	170	80	—	1,020	1,760	2,780
	22	9 57	p.m.	N. part of Shimosa.	60	40	—	160	520	680
March	1	3 16	p.m.	Off the E. coast of Hokkaido.	350	200	80	2,410	4,450	6,940
	5	8 21	p.m.	S. part of Rikuzen.	110	80	100	980	1,850	2,930
	7	11 50	a.m.	Off Cape Erimo (Hokkaido).	300	150	—	90	3,390	3,480
	10	7 16	p.m.	Central part of Higo.	100	50	30	500	1,620	2,150
	„	7 48	p.m.	Do.	90	60	40	790	2,440	3,270
	„	10 03	p.m.	Do.	130	90	200	1,740	1,490	3,430
	13	0 38	a.m.	Vicinity of Noda (Shimosa).	110	50	40	730	590	1,360
	18	2 07	p.m.	Off the coast of Iwaki.	180	140	140	1,010	1,800	2,950
	„	3 16	p.m.	Central part of Rikuchu.	80	60	—	270	570	840
	19	8 34	a.m.	Outside the Rikuzen Bay.	120	60	—	190	690	880
	23	7 28	p.m.	Off the S. coast of Shikoku.	250	150	—	190	3,420	3,610
	26	1 11	p.m.	Central part of Inland Sea.	90	50	—	750	1,310	2,060
	„	8 22	p.m.	Some distance off the E. coast of main Island.	600	400	—	3,200	5,600	8,800

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1907				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
March	30	6h21m p.m.	Boundary between Ise and Yamato.	120	60	80	530	1,010	1,620
	31	7 20 p.m.	Off the coast of Iwaki.	220	160	80	1,720	3,280	5,080
April	2	7 28 p.m.	Central part of Higo.	40	30	—	100	300	400
	9	0 23 p.m.	Off the coast of Bingo, (Inland Sea).	220	140	490	3,920	2,390	6,800
	11	8 47 a.m.	Off Cape Erimo (Hokkaido).	270	200	50	1,570	3,560	5,180
	13	4 05 a.m.	Central part of Higo.	60	40	100	630	550	1,280
	18	2 23 a.m.	Vicinity of Kasama (Hitachi).	70	40	—	100	470	570
	21	4 31 a.m.	Off the coast of Iwaki.	150	120	—	120	1,180	1,300
	23	9 58 a.m.	Do.	300	180	410	2,820	2,540	5,770
	25	4 48 a.m.	Vicinity of Suzaka (Shinano).	45	15	—	40	130	170
	,,	11 35 a.m.	Off Cape Erimo (Hokkaido).	140	120	—	30	370	400
	29	3 30 p.m.	Off the coast of Bingo (Inland Sea).	30	20	—	180	320	500
	30	5 56 a.m.	Rikuzen Bay.	120	80	—	370	1,550	1,920
	,,	0 51 p.m.	Off the coast of Hitachi.	160	110	270	810	1,630	2,710
May	4	5 37 p.m.	Vicinity of Ogasawara-jima.	600	400	10	—	450	460
	5	2 16 a.m.	Off the coast of Hitachi.	220	180	510	2,420	3,130	6,060
	9	7 25 a.m.	,, Rikuzen.	250	150	—	990	3,460	4,450
	10	7 42 a.m.	Off Cape Erimo (Hokkaido).	200	150	10	320	1,440	1,770
	14	4 49 a.m.	Off the SE coast of Nemuro.	100	40	50	320	520	890
	23	7 54 a.m.	Off the coast of Rikuzen.	250	150	—	1,440	2,760	4,200
	,,	9 18 p.m.	Off the coast of Bingo, (Inland Sea).	100	60	70	920	2,570	3,560
	,,	11 39 p.m.	Do.	70	30	—	170	1,560	1,730
	27	7 00 a.m.	S. part of Shimotsuke.	120	50	—	380	950	1,330
June	7	6 51 a.m.	Some distance off the E. coast of Kazusa and Awa.	400	200	—	100	630	730

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
			(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1907			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
June 11	8^h59^m a.m.	Off the NE. coast of Kazusa. $\varphi = 35° 30'N, \lambda = 140° 45'E.$	250	180	160	2,140	2,480	4,780
14	1 43 p.m.	,,	150	130	40	300	810	1,150
29	2 50 p.m.	Vicinity of Suzaka (Shinano).	80	70	30	250	470	750
July 1	11 48 a.m.	Off the coast of Hitachi.	130	80	—	220	920	1,140
2	5 45 a.m.	Vicinity of Kasumiga-ura.	120	100	—	250	930	1,180
4	9 17 p.m.	Off the N. coast of Formosa.	200	—	—	200	750	950
6	0 45 a.m.	,, Nemuro.	400	200	900	4,150	5,400	10,450
16	6 35 a.m.	Do.	60	40	—	270	550	820
24	1 16 a.m.	Off the coast of Kushiro.	80	70	—	350	620	970
26	8 10 p.m.	Off the E. coast of Mutsu.	110	60	—	250	510	760
27	4 23 p.m.	Vicinity of Kawawa (Musashi)	150	100	100	650	500	1,250
Aug. 1	3 47 p.m.	Central part of Formosa.	40	30	50	230	500	780
7	11 47 a.m.	Bungo Strait.	100	60	100	780	1,230	2,110
14	4 50 a.m.	Off the coast of Ugo.	170	140	170	1,560	2,460	4,190
26	8 54 a.m.	E. part of Izumo.	230	160	290	2,650	2,150	5,090
28	3 57 p.m.	Do.	70	40	—	210	560	770
31	4 04 p.m.	Off Kinkazan (Rikuzen).	130	80	—	120	530	650
Sept. 1	8 08 a.m.	Near Koshiki-jima, off the S. coast of Kyushu.	100	60	70	320	660	1,050
8	2 10 a.m.	Off the coast of Hidaka.	130	80	—	30	380	410
13	7 27 p.m.	E. part of Izumo.	70	35	—	430	480	910
15	6 01 p.m.	Off the coast of Hidaka.	230	150	110	1.200	1,600	2,910
,,	8 21 p.m.	Off the coast of Hidaka.	250	150	170	1,120	3,150	4,440
16	2 21 a.m.	E. part. of Izumo.	50	25	—	190	230	420

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) *Longer axis*	(5) *Shorter axis*	(6) *Slight motion*	(7) *Moderate motion*	(8) *Slight motion*	(9) *Sum*
1907					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Sept.	22	4 50	a.m.	Off the E. coast of Kazusa.	230	180	590	930	1,010	2,520
,,		9 08	p.m.	Off the S. end of Formosa.	150	—	—	20	300	320
Oct.	1	6 16	p.m.	Tokyo Bay.	80	40	—	40	260	300
	5	5 28	a.m.	Some distance off the coast of Iwaki.	300	200	—	1,380	4,130	5,510
	10	8 13	p.m.	In Lake Biwa.	40	20	—	90	180	270
	11	3 51	a.m.	Off the coast of Echizen.	120	100	30	1,110	2,040	3,180
	13	1 40	p.m.	Near the coast of Sagami.	60	30	10	140	210	360
	15	9 05	a.m.	Off the coast of Hitachi.	250	150	190	2,160	2,120	4,470
	24	5 14	a.m.	Near E. coast of Kii.	70	60	170	400	510	1,080
	27	3 46	p.m.	S. part of Hida.	140	100	210	1,490	2,400	4,100
	28	8 33	a.m.	Off the coast of Iwami.	100	50	—	300	590	890
	,,	5 54	p.m.	Do.	80	60	—	370	1,250	1,620
	,,	9 17	p.m.	Off the coast of Iwaki.	200	180	160	2,410	2,840	5,410
Nov.	4	6 03	a.m.	Near Koshiki-shima, off the S. coast of Kyushu.	70	60	—	70	410	480
	10	2 03	a.m.	Vicinity of Kawawa (Musashi)	50	40	—	30	170	200
	11	7 41	a.m.	Off the NE. coast of Rikuzen.	100	60	—	20	230	250
	13	11 11	a.m.	Off Cape Shiriya (Mutsu).	150	80	—	180	490	670
	21	1 32	p.m.	Tokyo Bay.	70	40	—	60	790	850
	22	2 17	a.m.	N. part of Musashi. $\varphi = 36° 15' N, \lambda = 139° 45' E$	200	120	1,420	2,310	2,830	6,560
	27	6 36	p.m.	Off cape Shiriya (Mutsu).	250	150	170	1,880	3,670	5,720
	28	11 28	a.m.	N. part of Shimosa.	35	20	—	70	490	560
	29	5 21	a.m.	Off the NE. coats of Rikuzen.	70	40	—	60	90	150
Dec.	2	10 53	p.m.	,, E. coast of Mutsu.	300	200	2,020	2,220	2,920	7,160
	3	8 23	a.m.	Formosa.	200	150	—	100	770	870

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total Area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1907				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Dec.	10	0 39 a.m.	Vicinity of Iwamurata (Shinano).	60	20	—	100	290	390
	11	5 54 p.m.	Vicinity of Chiba, Shimosa.	120	60	—	340	570	910
	15	6 09 a.m.	Sea of Amakusa (Kyushu).	120	70	—	20	330	350
	20	8 42 p.m.	Off the E. coast of Mutsu.	130	100	—	330	1,330	1,660
	23	10 14 a.m.	„ coast of Kushiro.	450	250	950	2,300	2,820	6,070

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On the Fore-shocks of Earthquakes.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pl. XXIII.

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1. *Introduction.* It often happens that precursory shakings, or "fore-shocks," of different intensities are felt at the epicentral district of a great earthquake. As the latter is generally due to the formation or enlargement of a fault or crack of considerable length along a seismic zone in the earth's crust, it is quite natural that some of the weakest secondary points at the strained region should first give way and produce the minor shocks, before the dislocation or fracture along the whole extension of the focus produces the final great disturbance. In many instances, the fore-shocks were quite numerous, some of them attaining the intensity of a semi-destructive motion. I mention next the more typical cases of the destructive earthquakes in Japan, which were preceded by these small shocks.

2. ***Earthquake of Kagi (Formosa) of 1906.*** The destructive earthquake in the Kagi prefecture, Formosa, on March 17, 1906, caused by the formation of the Baishiko and Chinsekiryo Faults, (the *Bulletin*, Vol. I, No. 2), was preceded about 5 minutes before by two strong shocks accompanied by very loud *jinari*, or sounds, like that due to a continuous discharge of gun. As these disturbances were quite unlike ordinary earthquakes felt there, the people were alarmed and took precaution for an escape in case of emergency, many running out of doors. Thus it happened that a comparatively small proportion of the inhabitants remained within doors at the time of the final great shock, a circumstance which must have considerably reduced the amount of casualties.

The occurrence of the premonitary shocks and *jinari* was also very striking in the cases of the Ansei and Riku-U earthquakes (§ § 3 and 4).

3. ***Ansei earthquake in Central Japan.****** The great earthquake of the 1st year of Ansei (1854), which was violently felt in the provinces of Iga, Ise, Omi, Yamato, Yamashiro, and Settsu, took place on July 9, at about 2 am.* The epifocus was a zone about 100 km. in length, which stretched from the vicinity of Yokkaichi (in Ise) to that of Nara (in Yamato), passing by the north of the town of Uyeno (in Iga), where considerable convulsions of the ground were produced. At the last named place, a moderate shock intense enough to drive people out of doors had been felt already two days before, namely, on the 7th, at 1 pm., succeeded by a stronger and unusually severe one at a little before 2 pm. These two shocks, which caused some cracks of the plastered walls, were followed by incessant *jinari*, or earth sounds, like thunders heard toward the north-west, the number of the minor shakings which occurred before the evening being 27. It is recorded that a traveller happening to arrive at Uyeno the same day was frightened by the *jinari*, so he went on and stayed at Kasagi, thereby escaping the risk of the disastrous earthquake. During the night of the 7th, the people were panic-stricken, no one going to bed. On the next day (the 8th), the weather was fine, and although the *jinari* did not cease, there was no specially severe shock, and the people began to be somewhat reassured. In the same evening, however, there were a few small shakings at about 8 pm., the final great earthquake having taken place the next morning at 2 am. The two shocks at 1 and 2 pm. on the 7th were also felt in Osaka.

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* This is different from the two great earthquakes of Dec. 23 and 24 in the same year, which originated off the Pacific coast of Japan. See also my note "On the earthquake zones in central Japan," the *Bulletin*, Vol. I, No. 3.

4. ***Riku-U earthquake of Aug. 31, 1896, at 5h 6m pm.*** The Riku-U earthquake was most violent in the two counties of Senpoku and Hiraga, in the province of Ugo, and in the county of Nishi-Waga in the province of Rikuchu, producing the lines of dislocations known as the Senya and Kawafune Faults. In the epicentral district, there had occurred a shock of moderate intensity already 6 days before, namely, on Aug. 23rd, at 4 pm., followed daily by one or more small shakings. On the 31st, at 9 am., there was a strong shock, causing some damage to the dwelling houses and throwing off the plastered walls of some old *dozo* (Japanese ware houses). Thereafter occurred nearly 30 shocks and *jinari*; amongst others the shock at 4h 42m pm. being the strongest. 24 minutes later on, at 5h 6m pm., the final great earthquake took place.

The epicentral district had, before August, 1896, been only rarely disturbed by earthquakes, and these latter had not been accompanied by *jinari*. But since the 23rd of August, the earthquakes were invariably accompanied by *jinari*, indicating their nature as fore-shocks and the proximity of their origins.

5. ***Tonan earthquake of Nov. 5, 1900, at 4h 41m pm.**** This earthquake originated off the coast of Izu, and was strongly felt in Kozu-shima, Mikura-jima, and Miyake-jima. At the last-named island, the first fore-shock, which was moderate in intensity, occurred at 8 am., on the 4th, followed by many moderate and slight shakings. At Mikura-jima, there was a moderate shock at 6 am., on the 5th, followed every five or ten minutes by others, the two strongest among which took place at 2 and 3 pm. respectively. In Kozu-shima, there was at 8h 10m am., on the 5th, a slight shock, followed by about a dozen moderate and slight ones, the final and largest earthquake having occurred at 4h 41m pm. the same day. According to the instrumental observations in Tokyo, there were 7 shocks, which preceded the final earthquake, and the first of which occurred at 9h 16m am., on the 5th, the strongest among these being that at 2h 10m pm.

6. ***Mino-Owari earthquake.*** The great Mino-Owari earthquake of Oct. 28, 1891, at 6h 37m am., was preceded by a strong shock, which took place 58 hours earlier, namely, at

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* "Tonan" islands are the islands off the coast of Izu belonging to the Fuji volcanic chain.

9h 14m pm., on the 25th of the same month. In the epicentral area, *jinari* were heard from time to time before the great earthquake.

7. *Hokkaido earthquake of March 22, 1894.* The earthquake of March 22, 1894, which caused damage in the two provinces of Nemuro and Kushiro, along the north-eastern coast of Hokkaido, occurred at 7h 20m pm., the origin being sub-oceanic and at about 140 km. to the south-east of the city of Nemuro. This earthquake was preceded by the four shocks, whose times of occurrence and the intensity of motion at Nemuro were as follows:—

(i)	3^h	49^m	14^s	am.	Slight.
(ii)	2	22	55	pm.	Moderate.
(iii)	2	33	25	pm.	Slight.
(iv)	2	37	10	pm.	„

Thus the first fore-shock and the 2nd, which was the strongest among the four, had occurred respectively 15h 30m and 4h 57m before the final great earthquake.

The above mentioned four fore-shocks were observed with the ordinary Gray-Milne-Ewing type seismographs. Had the observation been made with the modern sensitive tromometer adapted to a continuous recorder, probably there would have been registered many other small insensible shakings.

8. *Remarks on the fore-shocks of the different earthquakes.* The time distributions of the Riku-U and Tonan fore-shocks, which occurred on the same days as the principal earthquakes themselves, present some mutual resemblance, as will be seen from the following table.

TABLE I.—FORE-SHOCKS OF THE RIKU-U AND TONAN EARTHQUAKES.

Riku-U Earthquake.			Tonan Earthquake.		
Time of Occurrence.	Successive Interval.		Time of Occurrence.	Successive Interval.	
$9^{h}58^{m}$am.			$9^{h}\ 16^{m}$am.		
	$0^{h}\ 15^{m}$			$4^{h}\ 55^{m}$	
10 13 am.			2 11 pm.		
	4 54	**$5^{h}\ 20^{m}$**		0 37	**$5^{h}\ 38^{m}$**
3 07 pm.			2 48 pm.		
	0 11			0 06	
3 18 pm.			2 54 pm.		
		1 24		0 13	
4 42 pm.			3 07 pm.		**1 21**
				1 8	
			4 15 pm.		
		0 24			**0 27**
5 06 pm. (Great Eqke.)			4 42 pm.		

Thus the successive intervals between the times of occurrence of the fore-shocks were on the whole identical for the Riku-U and the Tonan earthquakes; the last strong fore-shocks having also occurred in the two cases by a nearly equal time interval, namely, 24 and 27 minutes respectively before the final disturbances.

The interval between the times of occurrence of the first strong fore-shock and the final great earthquake was, for the different cases, as follows:—

Ansei Eqke.	1^{day}	13^{hours}
Riku-U „	6	1
Tonan „	1	9
Mino-Owari Eqke.	2	10
Hokkaido „	0	15½

Again, the interval between the time of occurrence of the principal disturbance and the commencement of the last epoch of increased activity or frequency of the fore-shocks, was as follows :—

Ansei	Eqke.	6^h	0^m
Riku-U	,,	8	34
Tonan	,,	7	26
Hokkaido	,,	4	57

The occurrence of fore-shocks is of course not limited to the few cases of the great earthquakes considered in § § 2 to 7. The same phenomena are shown by the large as well as the semi-destructive or strong earthquakes originating off the north-eastern coasts of Japan, along the Fuji volcanic chain, or off the eastern coast of Formosa. A few illustrative cases are given next.

9. ***Hokkaido earthquake of June 4, 1893.*** The earthquake of June 4, 1893, at 2h 27m am., shook the southern islands of the Kuriles. Thus, in Shikitan island, the shock was felt strongly, being followed by the *tsunami* along the coast, which reached a height of about 8 feet over the ordinary sea level. Again, in the Shibetori county (northern part of the Etrup island), the *tsunami* came on about 20 minutes after the shock, and caused an increase of water of 5 feet, forcing the river waters to flow upwards. The *tsunami* continued till 9 am., and the large waves were repeated five times, rocks having been thrown down at many places along the coast. Prior to this earthquake, there had occurred between the 1st and 3rd (June), five moderate and slight earthquakes, which shook the Kuriles or the eastern part of Hokkaido; there being one or more shocks each day between the 4th and the 13th, except the 10th and the 12th.

10. ***Karenko (Formosa) earthquake of 1905.****[*] The earthquake of Aug. 28, 1905, at 1h 24m pm., which was a local earthquake and which was semi-destructive at Karenko (Formosa), was preceded by several fore-shocks. Thus, at the latter town, there was a shock on the fore-noon of Aug. 8, several on the 13th, one each on the 18th, 19th, 20th, and 21st. A moderately strong shock occurred on the 26th, at 4h 50m pm., followed by a few slight ones, the final strong earthquake having taken place on the 28th. The after-shocks were also numerous, there being 20 or 30 of these on the same day and on the 29th.

11. ***Oshima (Izu) earthquakes of June 6 and 7, 1905.*** These two earthquakes, which caused some damage in the island of Oshima (Izu), were preceded by numerous small shocks. According to the report of the Governor of the island, there were more than 30 shakings between 1 am. and 10h 15m am., on the 5th, and a strong earthquake took place at 0h 35m am., on the 6th, causing several landslips in the island. The subsequent shocks were very frequent, more than 100 having happened before 11 am. the same day. On the 7th, at 2h 39m pm., there took place the principal earthquake, which were followed by more than 50 after-shocks in the course of the next 12 hours.

According to the tromometer observation in Tokyo, the first shock occurred on the 5th, at 10h 23m 26s am., between which time and the midnight of the 7th there were 28 others. Of these the 22nd one, which gave the greatest diagram, took place on the 7th at 2h 39m 30s pm. The following table gives a list of the earthquakes observed on the 5th to 7th in Tokyo.

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[*] See my note on the Bokusekikaku and Basshisho earthquake of Jan. 11, 1908, given elsewhere in this Number.

TABLE II.—OSHIMA (IZU) EARTHQUAKES OBSERVED IN TOKYO.

No.	Group.	Intensity in Tokyo. (*....Unfelt)	Time of Occurrence in Tokyo.	Mean Time of Occurrence in Tokyo.
1		*	5th $10^h 23^m 26^s$ am.	
2	A	*(*Strong* in Oshima)	6th 0 40 34 ,,	**2 08 44** am.
3		*	0 43 37 ,,	
4		*	0 59 16 ,,	
5		*	1 13 43 ,,	
6		*(*Moderate* at Yokohama)	1 19 21 ,,	
7		*	1 38 56 ,,	
8		Slight (*Moderate* at Mera)	1 50 50 ,,	
9		*(*Moderate* at Yokohama)	2 05 09 ,,	
10		Slight (*Moderate* at Mera)	2 22 53 ,,	
11		*	2 50 45 ,,	
12		*	4 42 27 ,,	
13		*(*Moderate* at Yokohama)	5 17 13 ,,	
14	B	*	9 19 57 ,,	**10 53 14** am.
15		*	9 23 08 ,,	
16		*	10 23 30 ,,	
17		*	0 30 14 pm.	
18		*	0 49 22 ,,	
19	C	*	5 28 22 ,,	**7 28 39** pm.
20		*	9 28 55 ,,	
21	D	*	7th 6 12 05 am.	**6 12 05** am.
22	E	Slight(*Strong* in Oshima, rather *strong* at Yokohama.)	2 29 30 pm.	**2 39 30** pm.
23	After-shocks.	*	3 30 41 ,,	
24		*	3 44 18 ,,	
25		*	4 13 58 ,,	
26		*	8 43 54 ,,	
27		*	10 06 51 ,,	
28		*	11 09 18 ,,	

From the above table it will be seen that the 12 shocks, Nos. 2 to 13, occurred one closely after the other. Similarly the 5 shocks, Nos. 14 to 18, occurred together, being, however, separated from the preceding ones by a long interval. Thus the 21 shocks, Nos. 2 to 22, the last of which was the principal earthquake, may be divided more or less definitely into the five groups, A, B, C, D, and E, whose mean times of occurrence are found to be as follows :—

						Time Interval.
A (12 shocks)	6th :	2^h	8^m	44^s	am.	
						8^h 45^m
B (5 ,,)		10	53	14	,,	
						8 35
C (2 ,,)		7	28	39	pm.	
						10 43
D (1 ,,)	7th :	6	12	05	am.	
						8 27
E (1 ,,)		2	39	30	pm.	

The successive intervals between the mean times of occurrence, which may be regarded as indicating the most active epoch of the different groups, were approximately equal to one another, varying from 8h 27m to 10h 43m. Further, the numbers of the shocks in the first four groups were respectively 12, 5, 2, and 1. That is to say, the fore-shocks of the earthquake, No. 22, occurred periodically in groups at a mean interval of about 8½ to 10½ hours, the activity or frequency being successively lessened, till the principal disturbance finally took place. This time relation of the fore-shocks is somewhat similar to that in the case of the Ansei earthquake of July 9, 1854.

The shocks, Nos. 23 to 28, were the after-shocks. It seems that on the occasion under consideration the fore-shocks were more numerous than the after-shocks.

12. ***Hachijo-jima earthquakes of May 13, 1908.*** The two principal earthquakes on May 13, 1908, at 5h 23m and 5h

37m am., originated under the ocean nearly midway between the Cape Omae-zaki of Totomi and the island of Hachijo-jima, at a distance of about 100 km. to the north-west of the latter.* There were 5 fore-shocks, which were registered at the meteorological observatory of Hachijo-jima on the Omori horizontal pendulum tromometer of 150 times in the EW direction, the results of the observation being shown in Table III. (See the diagram reproduced in Pl. XXIII.)

TABLE III.—EARTHQUAKE OBSERVATION AT HACHIJO-JIMA.

(Nos. 1–5 are fore-shocks).

No.	Time of occurrence at Hachijo-jima. (May 13)	Intensity.	Duration of		Max. 2a.	Difference between the successive times of occurrence.
			Total Eqke.	Preliminary Tremor.		
1	$4^h 44^m 13^s$ am.	Insensible.	$1^m 15^s$	16.0^{sec}	0.043^{mm}	22^m 37^s
2	5 06 50	„	2 25	16.3	0.16	8 43
3	5 15 33	„	0 35	—	0.017	3 57
4	5 19 30	„	0 30	—	0.024	2 13
5	5 21 43	„	0 30	16.8	0.027	1 26
6	5 23 09	Strong.	Longer than 10^m	15.2	Large.	
7	5 37 55	„	Do.	—	Do.	

The time difference between the 1st and 2nd shocks was 22m 37s, while that between the 2nd and 3rd shocks was shorter and 8m 43s. The succeeding three intervals again decreased and were respectively 3m 57s, 2m 13s, and 1m 26s. Thus in the present case, the fore-shocks, the first of which had occurred 39m before the principal earthquake, quickly increased in frequency till the latter was finally produced, indicating a rapid progress of disturbance at the focus.

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* These two earthquakes are discussed more in detail elsewhere in this Number.

13. ***Distinction between local and large earthquakes.*** A local shock, which may be regarded as originating from a centre or point and is sometimes destructive at the epicentre, is characterized by the smallness of its total energy. Such a disturbance seems generally to be unaccompanied by the fore-shocks. On the other hand, large earthquakes, whose focus has a considerable extension and may be regarded as being equivalent to a collection of a great number of local centres of disturbance arranged along a zone, seem to be preceded on many occasions by minor shocks. The fore-shocks of a great earthquake may first occur several days or several hours before the latter, and their time distribution may be sometimes more or less periodical.

The phenomena of fore-shocks furnish a very interesting subject of study, and give a practical importance to the tromometrical observation in earthquake countries. My belief is that a large destructive earthquake will be foretold in its epicentral region by some fore-shocks.

Tokyo. May, 1908.

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Notes on the Secondary Causes of Earthquakes.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XXIV-XXVIII.

CONTENTS.

§ 1. Introduction.
§ 2. Examples of local characteristics.
§ 3. Strong earthquakes in Shimosa and Hitachi.
§ 4. General relations of the secondary causes to earthquake frequency.
§ 5. *Jinari* at Arima, 1899-1900.
§ 6. Diurnal variation of earthquake frequency in Tokyo.
§ 7. Precipitation and yearly earthquake frequency in Tokyo.
§ 8. Weather and destructive earthquakes.
§ 9. Earthquake weather and fires.
§ 10. Effects of barometric pressure and tides.
§ 11. Stronger earthquakes originating from the Izu Islands zone.
§ 12. Recent strong earthquakes felt in Tokyo.
§ 13. List of the stronger earthquakes whose origins were not much distant from Tokyo.
§ 14. Conclusion.

1. ***Introduction.*** Earthquakes are caused by some sudden underground disturbances, which may consist in the formation or extension of a fault, the production of a fissure or cavity, the subsidence or upheaval of a piece of ground, etc. These disturbances themselves are, however, the results of the stresses going on in the earth's crust for a considerable interval of time; a great shock at a given portion of a seismic region occurring in general only once in several years or even several centuries. When, therefore, an earthquake is about to happen, the earth's crust in the vicinity of its focus is in a critical condition and must be very sensitive to the effects of changes in the atmospheric pressure, the amount of precipitation of rain and snow, the variation in the weight of the sea water in the tidal movement, etc. These external agencies, which constitute the *secondary earthquake causes* have evidently an important bearing on the seismic phenomena, and the present paper contains some notes on the relations of these to the time distribution of the shocks in Japan.*

2. ***Examples of local characteristics.*** The following are some examples of the cases, in which strong or great earthquakes in a given region occurred in approximately the same parts of the year or of the day.

(*a*) The destructive earthquake of Kumamoto (Kyushu) took place on July 28, 1889. Its numerous after-shocks gradually decreased in frequency till 1894, when a strong earthquake occurred on Aug. 8. A third strong shock took place on Aug. 27, 1905, followed by a fourth on March 10, 1907. The times of occurrence of these 4 earthquakes, the three last of which were not destructive, are given in the following table.

TABLE I.—LIST OF THE SEVERE KUMAMOTO EARTHQUAKES.

No.	Date.	Time of Occurrence.
1	July 28, 1889.	$11^h\ 40^m$ pm.
2	Aug. 8, 1894.	11 19 „
3	Aug. 27, 1902.	10 42 „
4	March 10, 1907.	10 03 „

(*b*) The severe earthquake of May 26, 1898, at $3^h\ 0^m\ 0^s$ am., which caused some slight damage, originated in the District of Uonuma, near the town of Muikamachi, in the province of Echigo. Six years later, namely, in 1904, a second severe earthquake took place on May 8, at 4h 23m 49s am., the origin being close to that of the preceding shock.

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* The times are always given in the 1st Normal Japan Time, or that of longitude 135° E., of Greenwich.

(*c*) The great sea-waves of 1896 along the north-eastern coast of the Main Island, known as the Sanriku* *tsunami*, were caused by an earthquake, which took place on June 15, at 7½ pm. Five years later, namely, in 1901, there was also some tidal disturbances accompanying an earthquake which occurred on June 15, at 6½ pm.

(*d*) The great Shonai earthquake of 1894, which caused enormous damage to life and property in the city of Sakata and the vicinity (provinces of Uzen and Ugo), took place on Oct. 22, at 5h 35m pm. The great Riku-U earthquake of 1896 took place on Aug. 31, at 5h 6m pm.

Thus it will be seen that the first three Kumamoto earthquakes, (*a*), were in July or August, while all the four occurred late in the evening, namely, between 10h 03m pm. and 11h 40m pm. The two Echigo earthquakes, (*b*), took place in the month of May, at 3h 0m to 4h 23m am. The two Sanriku earthquakes, (*c*), occurred on June 15, at 6½ to 7½ pm. Finally, the two great destructive earthquakes of Northern Japan, (*d*), occurred at 5h 6m to 5h 35m pm.

From these examples it may be inferred that great and strong earthquakes in a given district often have a tendency to occur in certain months of the year, or at certain hours of the day. This is to be regarded as indicating the local peculiarities, probably depending on the tidal movement of the sea water and the annual and diurnal variations of the barometric pressure. As an example relating to great earthquakes occurring along an extensive seismic zone, I mention the four recent destructive shocks of San Francisco, Mexico, and Central America, whose dates were as follows :—

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* *Sanriku* denotes the three large provinces of Rikuzen, Rikuchu, and Mutsu, which form the north-eastern part of the Main Island.

TABLE II.—EARTHQUAKES ALONG THE SOUTH-WESTERN COAST OF NORTH AMERICA.

Date.	Earthquake.
April 19, 1902.	Guatemala.
„ 18, 1906.	Earthquake of San Francisco.
„ 15, 1907.	Mexico.
March 26, 1908.	„

Thus the first three shocks occurred all in the month of April, between 15th and 19th, while the 4th occurred in the latter part of March.

3. ***Strong earthquakes in Shimosa and Hitachi.*** The following table is a list of the earthquakes felt strongly at Mizukaido, Sahara and other places along the lower course of the Tone-*gawa*, which forms the boundary between the two provinces of Shimosa and Hitachi. The land areas of disturbance, within which the motion was sensible or was recorded by the ordinary Gray-Milne-Ewing type seismographs, were in each case over 1,000 sq. *ri.*

TABLE III.—STRONG EARTHQUAKES IN SHIMOSA AND HITACHI.

No.	Date.	Time of Earthquake Occurrence.
1	March 3, 1902.	9^h 13^m am.
2	„ 25, „	2 35 pm.
3	Aug. 8, „	8 37 am.
4	Dec. 14, „	1 57 pm.
5	„ 31, „	2 38 pm.
6	May 8, 1904.	7 24 am.
7	June 30, „	8 21 am.

It will be observed that four of the seven earthquakes given in the above table, namely, Nos. 1, 3, 6, and 7, occurred at 7 to 9 am., while the remaining three, Nos. 2, 4, and 5, occurred at 1 to 2 pm. These two groups of the times of occurrence may be regarded as approximately agreeing with a pair of epochs of the maximum and minimum in the diurnal variation of the barometric pressure.

4. ***General relations of the secondary causes on earthquake frequency.*** The secondary causes of earthquakes as enumerated in § 1 make themselves sensible by the variation of the vertical pressure exerted on the earth's crust. Let us examine a few simple cases of the relations of the secondary causes to earthquake frequency.

(*a*) Suppose *ab* to be a horizontal layer of the earth's crust, which is undergoing a tension parallel to its plane. Then an increase or decrease in the pressure, *c*, applied vertically to it, will equally accelerate the formation of a vertical rupture or crack. (Figs. 1 and 2.) In the case the layer *ab* is undergoing a compression in its plane, a variation in the external pressure may tend to produce a dislocation or slipping.

(*b*) When the layer *ab* is being pushed upwards from below, a decrease in the barometric pressure, the weight of the sea waters, etc., will favour the occurrence of the rupture.

(*c*) When the layer *ab* is being pushed down, the increase in the pressure due to the secondary causes will tend to the same result.

Fig. 1.

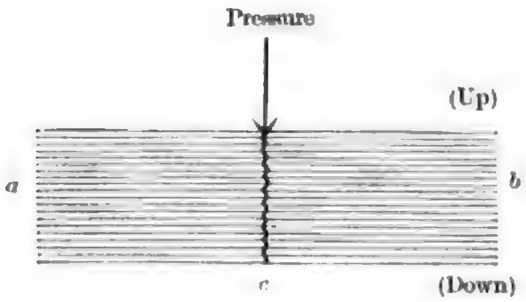
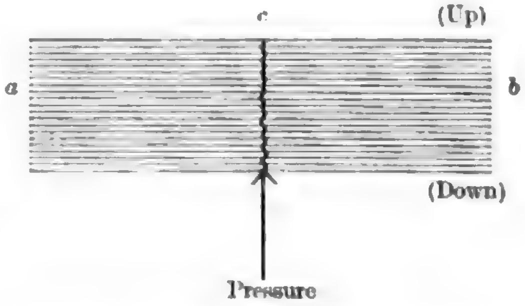


Fig. 2.



I give next a few cases illustrating some of these principles.

5. *Jinari* at Arima, 1899-1900.* The earth sounds, or *jinari*, at the famous hot spring place of Arima, near Kobe (province of Settsu), began on July 5, 1899, and were very numerous during the several succeding weeks. The maximum daily number, probably about 200, was reached at the beginning of August, thence the frequency gradually decreasing. After the 8th of August, the times of occurrence of these *jinari* were carefully recorded at the city office of Arima; the total number during the rest of the month being 584. In the four months of September to December

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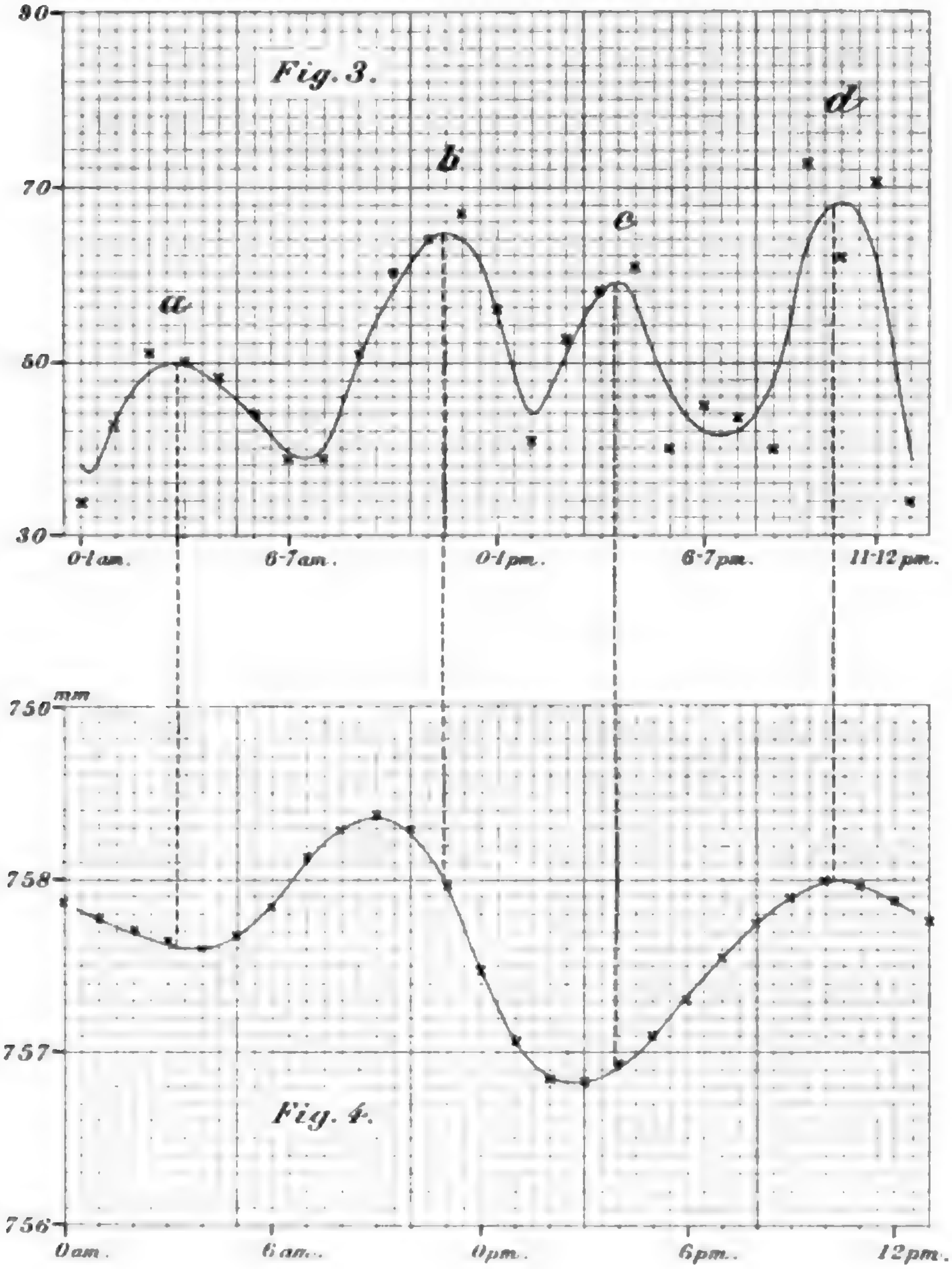
* The Japanese word "jinari," which signifies *earth sound*, may be used to denote earthquake sounds as well as those sounds heard in volcanic and other districts which are accompanied only by very slight tremblings of the ground.

Diurnal Variations.

Fig. 3. …… **Frequency of the *Jinari* at Arima.**
Fig. 4. …… **Barometric Pressure at Kobe.**



there were altogether 650 of the *jinari*, which did not completely cease in the course of the next year.

The origin of disturbance was situated at a distance of about 2 km to the south of Arima among the Rokko Mountain, whose formation is of granite and diorite. Judging from the frequency distribution of the *jinari* in the vicinity, the focal depth was very small, and probably between ½ and 2 km. The sounds, which were sometimes very loud, were mostly like that caused by the discharge of gun at a distance, or falling of a heavy mass on the ground. The tremblings of the ground, which followed the sounds after an interval of 0.5 to 1.0 second, were generally slight. On a few occasions, however, the earthquake mevement was quite sharp, and caused the falling down of some roof tiles, rolling down of rock fragments from mountain slopes, etc.

Table IV gives the hourly distribution of the 1,234 *jinari* recorded at Arima between Aug. 8 and Dec. 31, 1899, and the mean hourly barometric height during the same interval for the meteorological observatory of Kobe, which was not much distant from the origin of disturbance.

TABLE IV.—DIURNAL VARIATIONS OF THE FREQUENCY OF THE *JINARI* AT ARIMA AND THE BAROMETRIC PRESSURE AT KOBE.

Jinari at Arima.		Atmospheric Pressure at Kobe.	
Hour Interval.	Number of *jinari*.	Hour.	Barometric Height.*
0^h— 1^h AM.	34	1^h AM.	$700+57.78^{mm}$
1— 2	43	2	57.72
2— 3	51	3	57.66
3— 4	50	4	57.61
4— 5	48	5	57.68

Jinari at Arima.		Atmospheric Pressure at Kobe.	
Hour Interval.	Number of *jinari*.	Hour.	Barometric Height.*
5^{h}—6^{h} AM.	44	6^{h} AM.	$\overset{\text{mm}}{57.85}$
6—7	39	7	58.15
7—8	39	8	58.29
8—9	51	9	58.39
9—10	60	10	58.30
10—11	64	11	57.98
11—12	67	Noon	57.50
0—1 PM.	56	1 PM.	57.07
1—2	41	2	56.85
2—3	53	3	56.84
3—4	58	4	56.95
4—5	61	5	57.11
5—6	40	6	57.30
6—7	45	7	57.56
7—8	44	8	57.76
8—9	40	9	57.91
9—10	73	10	58.02
10—11	62	11	57.98
11—12	71	Midnight.	57.88
Sum	**1234**		
Mean	**51.4**		

* Reduction to standard gravity = −0.70 mm.
Reduction to mean sea level = +5.40 mm.

As illustrated in Fig. 3, the diurnal variation of the frequency of the *jinari* at Arima shows very clearly 4 maxima *a*, *b*, *c*, *d*, and the 4 corresponding minima, indicating a six-hour periodicity. Further, it will be observed from Fig. 4 that the diurnal variation of the barometric pressure at Kobe shows the two maxima and two minima, indicating as usual a 12-hour periodicity. Comparing the two figures, we see that the mutual relation between the *jinari* frequency and the barometric pressure is striking, the two maxima, *b* and *d*, and the two other maxima, *a* and *c*, of the former occurring nearly at the same hours respectively with the two maxima and minima of the latter. The epochs of the 4 maxima *a*, *b*, *c*, *d*, indicated by the mean frequency curve of the *jinari* are as follows :—

1st	Maximum,	(*a*)	about 3 am.
2nd	,,	(*b*)	,, 11 ,,
3rd	,,	(*c*)	,, 4 pm.
4th	,,	(*d*)	between 10-11 ,,

The differences between the 4 maxima *a*, *c*, *b*, *d*, and the corresponding minima (the preceding minimum in each case, say), are as follows :—

	Difference in the frequency.
1st Max. and Min.	17
2nd ,,	28
3rd ,,	20
4th ,,	33
Average	**25**

This average difference may approximately be regarded as the effect due to the barometric pressure, and corresponds to about 50% of the mean hourly frequency, namely, 51.4.

As the *jinari* are purely local phenomena of a shallow origin, it is to be quite expected that their frequency should be influenced by the barometric pressure. What was said above indicates that both the increase and the decrease of the pressure equally causes an increase in the frequency of the *jinari*, in accordance with the principle stated in § 4, (a).

6. ***Diurnal variation of earthquake frequency in Tokyo.*** The diurnal variation of the seismic frequency in Tokyo also shows clearly the same characteristic as the *jinari* at Arima. The following table gives the distribution in the 24 hours of the day of 2,208 earthquakes instrumentally observed during the 24 years, 1876–1899, at the Central Meteorological Observatory, and the mean hourly values of the barometric pressure at the same place.*

TABLE V.—DIURNAL VARIATIONS OF THE FREQUENCY OF EARTHQUAKES AND THE BAROMETRIC PRESSURE, IN TOKYO.

Earthquakes (1876–1899).		Atmospheric Pressure.	
Hour Interval.	Frequency.	Hour.	Barometric Height.†
0^{h}— 1^{h} AM.	92	1^{h} AM.	$700 + 59.33^{mm}$
1— 2	81	2	59.24
2— 3	90	3	59.18
3— 4	85	4	59.21
4— 5	71	5	59.35
5— 6	87	6	59.58
6— 7	95	7	59.79
7— 8	92	8	59.95
8— 9	96	9	60.00
9—10	113	10	59.88
10—11	93	11	59.49
11—12	84	Noon	58.98
0— 1 PM.	79	1 PM.	58.56
1— 2	91	2	58.31
2— 3	85	3	58.27

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* Reproduced from the *Publications of the Earthquake Investigation Committee*, No. 8.

† With the freezing point correction. Reduction to standard gravity = −0.63 mm; reduction to sea-level = +1.94 mm.

Pl. XXV.

Diurnal Variations. Tokyo.

Fig. 5. Seismic Frequency.

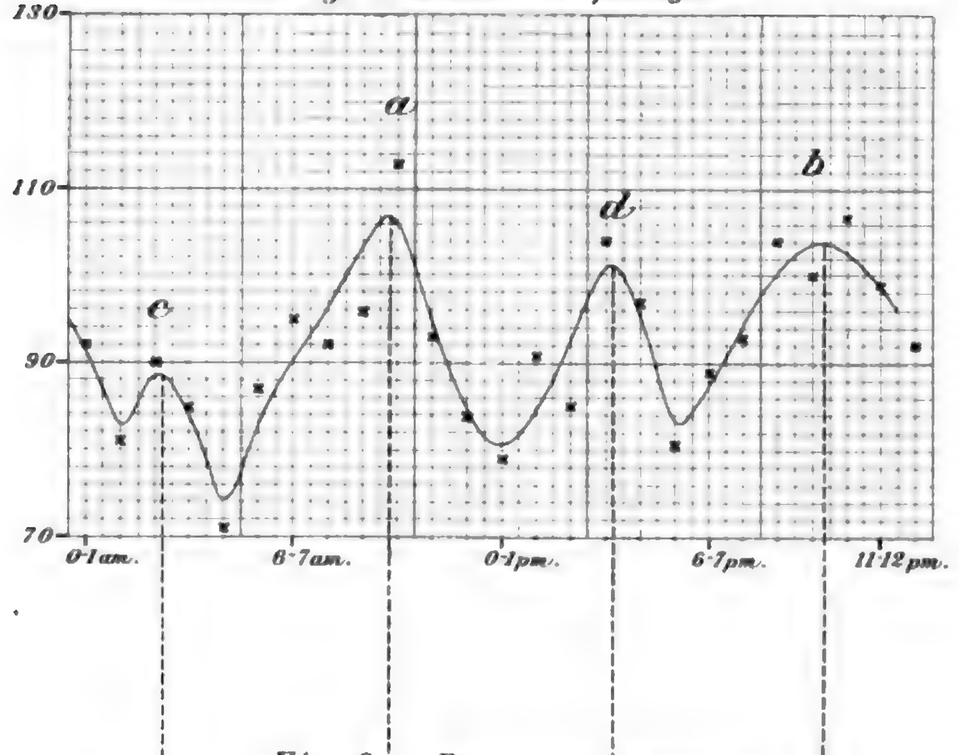
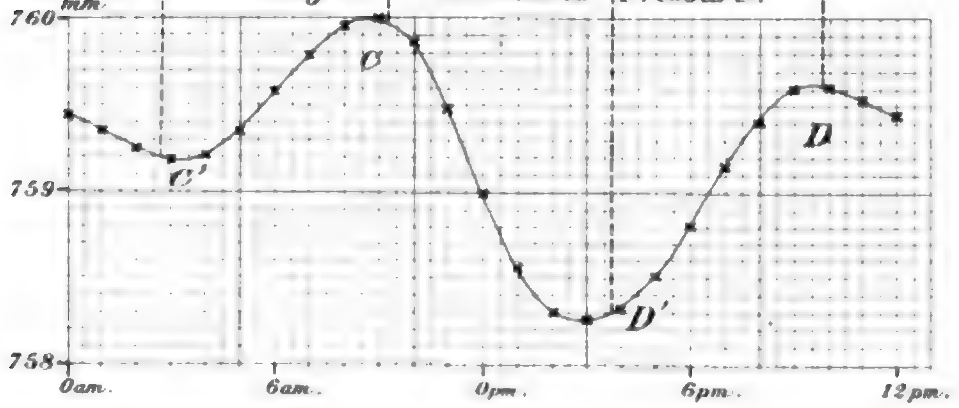


Fig. 6 Barometric Pressure.



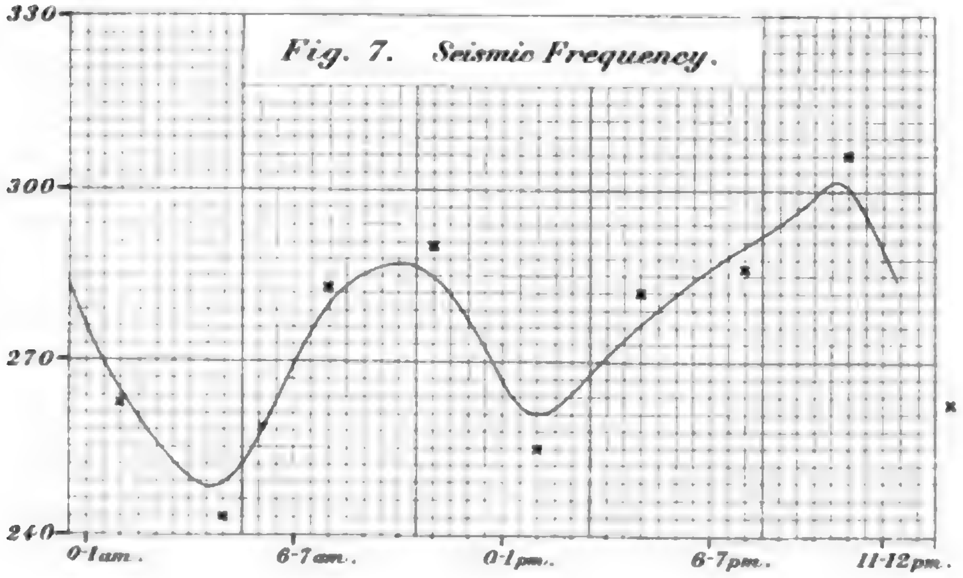


Fig. 7. Seismic Frequency.

TABLE V. *(Cont.)*

Earthquakes (1876-1899).		Atmospheric Pressure.	
Hour Interval.	Frequency.	Hour.	Barometric Height.
3^h— 4^h PM.	104	4 PM.	$700+58.33^{mm}$
4— 5	97	5	58.52
5— 6	81	6	58.82
6— 7	89	7	59.14
7— 8	93	8	59.40
8— 9	104	9	59.60
9—10	100	10	59.61
10—11	107	11	59.54
11—12	99	Midnight.	59.43

Fig. 7, drawn from the 3-hourly earthquake numbers, represents the mean course of the diurnal variation of the seismic frequency, which will be seen to be on the whole parallel to that of the atmospheric pressure. That is to say, the ordinary (non-destructive) earthquakes felt in Tokyo happen more frequently with the high barometer than with the low, illustrating a case stated in § 4, (*c*). The curve of the hourly seismic frequency (Fig. 5) indicates, however, 4 maxima, namely, a pair of principal maxima, *a* and *b*, respectively at 9–10 am. and 9–10 pm., and a pair of the secondary maxima, *c* and *d*, respectively at 2–3 am. and 3–4 pm. On comparing Figs. 5 and 6, it will be noted that, according to the principle of § 4, (*a*), the two maxima, *C* and *D*, and the two minima, *C′* and *D′*, of the barometric pressure correspond respectively to the pair of the principal maxima and the pair of the secondary maxima, of the seismic frequency.

7. *Precipitation and yearly earthquake frequency in Tokyo.* It is quite conceivable that the yearly earthquake frequency in Tokyo is related to the amount of the precipitation of rain and snow in the plain of Musashi, on which the city is situated, or along the north-western coast of the Main Island, where a large amount of the moisture is deposited during the winter months. I give in the second column of Table VI, the yearly numbers of the earthquakes which were not teleseismic and which were instrumentally recorded during the 32 years, 1876–1907, at the Central Meteorological Observatory. The observations were made at first with Palmieri's seismograph, but since 1887 by means of a Gray-Milne-Ewing type seismograph. It will be observed that the earthquake number was minimum (=32) in 1883, and maximum (=216) in 1896, thence the frequency is on the whole decreasing. For the sake of reference, I give in Table VII, the mean barometric pressure and temperature, and the amount of precipitation in Tokyo during each of these 32 years. As a trial I have taken into consideration the amount of precipitation at Niigata and Akita, both situated along the Japan Sea coast, as the observations at these two places date since 1882 and 1883, respectively over the long intervals of 26 and 25 years (Table VI). The city of Niigata, about 260 km to the NNW of Tokyo, is situated at the mouth of the Shinano-*gawa*, the quarternary plain about the lower course of the latter and the neighbouring rivers being the largest in Japan next to the Tokyo plain. The city of Akita is at about 440 km to the north of Tokyo.

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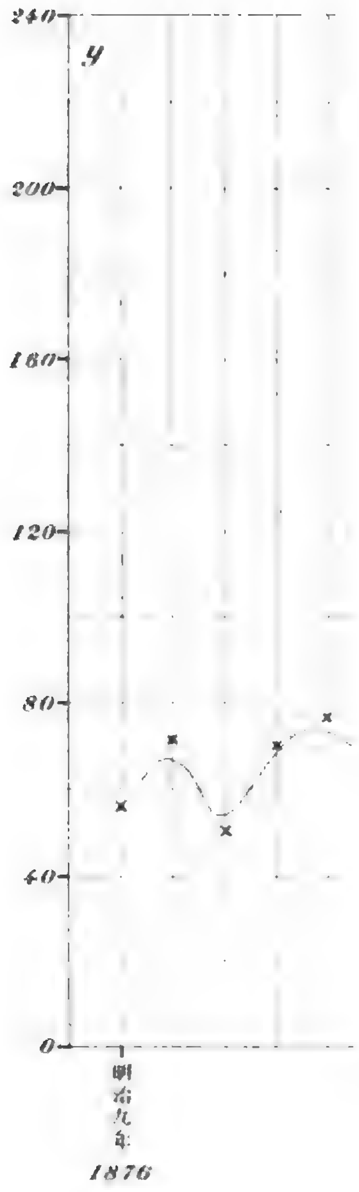
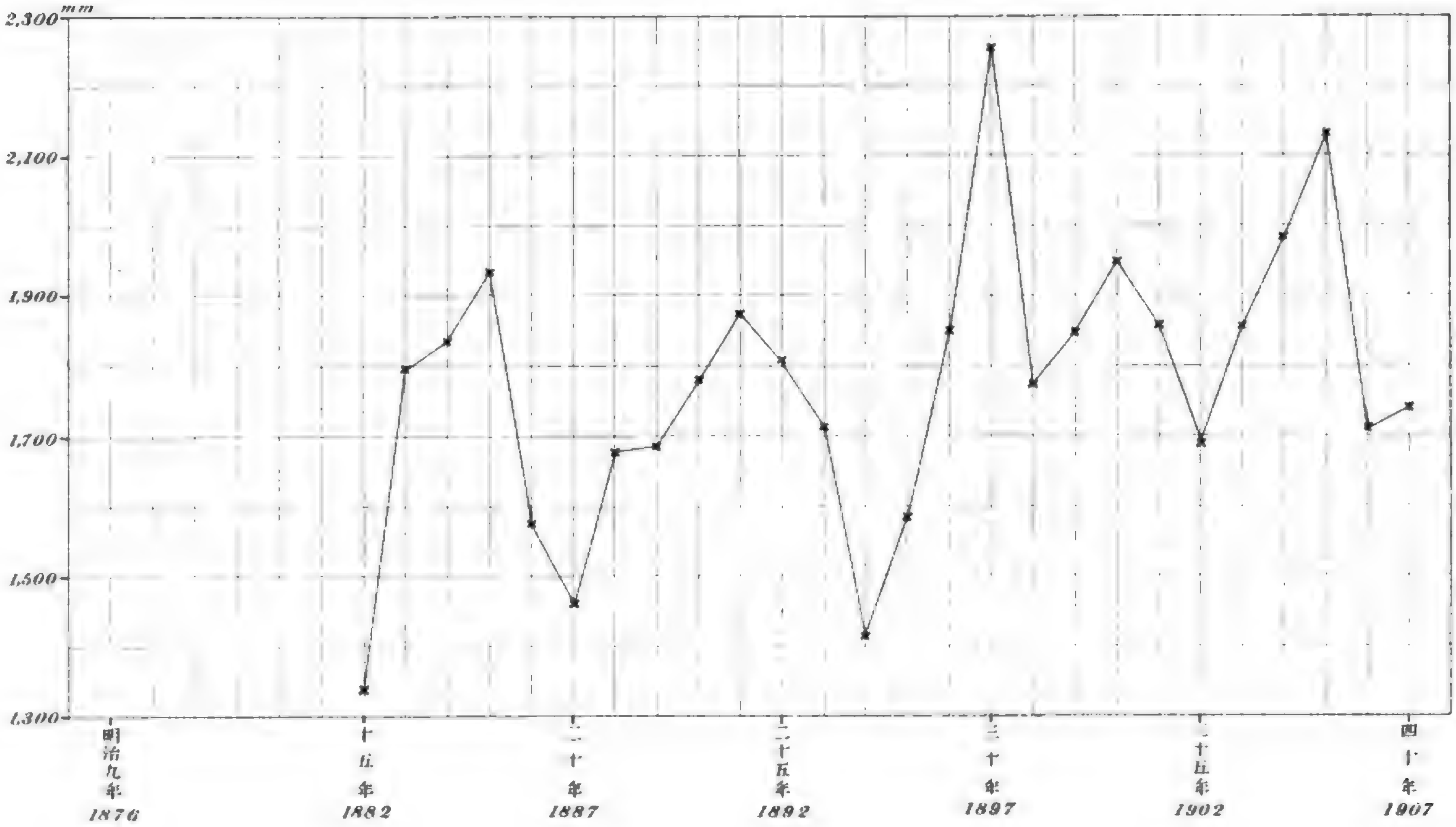


Pl. XXVII.

Fig. 9. Variation of the Yearly Amount of the Precipitation at Niigata.
1882–1907.



Pl. XXVIII.

Fig. 10. Variation of the Yearly Amount of the Precipitation at Akita. 1883-1907.

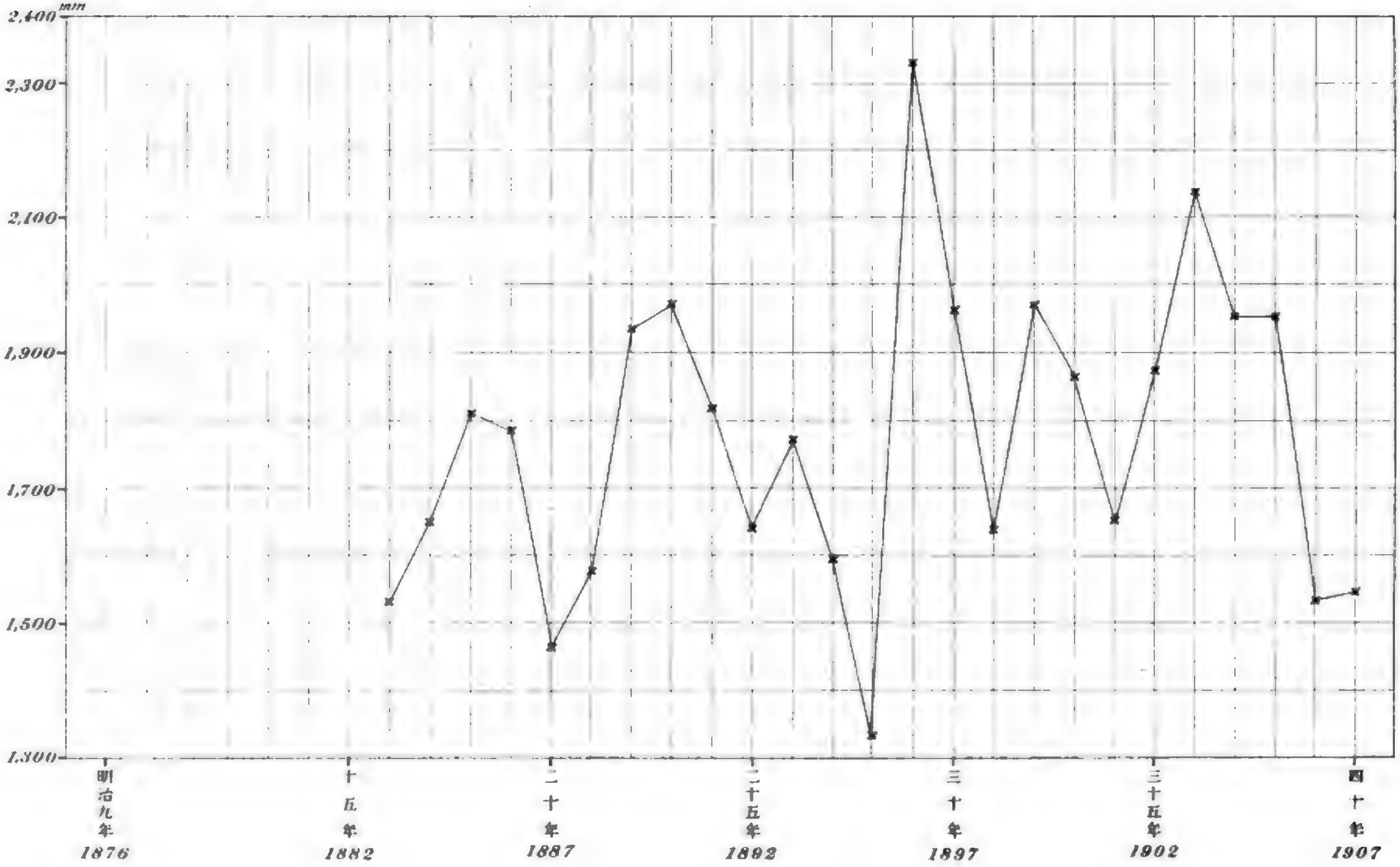


TABLE VI.—YEARLY NUMBERS OF EARTHQUAKES IN TOKYO, (1876-1907) AND THE AMOUNT OF PRECIPITATION AT NIIGATA AND AKITA (1882-1907.)

Year.	Number of Earthquakes in Tokyo.	Amount of Precipitation.		
		Niigata.	Akita.	*Mean.*
1876	56			
1877	71			
1878	50			
1879	70			
1880	77			
1881	64			
1882	46	1341.3^{mm}	—^{mm}	—^{mm}
1883	32	1796.5	1536.4	1666.5
1884	68	1839.3	1650.1	1744.7
1885	68	1935.9	1809.5	1872.7
1886	54	1580.1	1786.0	1683.1
1887	80	1467.9	1465.3	1466.6
1888	101	1681.3	1579.6	1630.5
1889	113	1889.3	1937.6	1913.5
1890	93	1784.0	1971.6	1877.8
1891	123	1877.7	1820.0	1848.9
1892	73	1809.9	1641.4	1725.7
1893	59	1717.9	1775.2	1746.6
1894	101	1418.0	1596.1	1507.1
1895	122	1586.7	1331.0	1458.9
1896	216	1854.1	2335.1	2094.6
1897	164	2257.8	1964.5	2111.2
1898	144	1777.6	1639.0	1708.3
1899	124	1853.0	1972.3	1912.7
1900	156	1953.3	1864.0	1908.7
1901	121	1861.4	1651.6	1756.5
1902	116	1693.3	1853.8	1773.6
1903	104	1858.9	2141.4	2000.2
1904	155	1986.5	1956.2	1971.4
1905	154	2133.5	1957.2	2045.4
1906	132	1713.2	1535.0	1624.1
1907	100	1741.7	1548.8	1645.3

TABLE VII.—MEAN BAROMETRIC PRESSURE AND TEMPERATURE, AND THE AMOUNT OF PRECIPITATION.

TOKYO. 1876–1907.

Year	Mean Barometric Pressure.*	Mean Temperature.	Annual Amount of Precipitation.
	mm	°	mm
1876	761.1	13.6 C	1756.4
1877	61.5	13.9	1317.3
1878	61.5	13.6	1764.2
1879	61.0	14.4	1492.7
1880	61.3	13.9	1685.7
1881	61.4	13.6	1444.4
1882	61.5	13.8	1478.3
1883	61.4	13.2	1552.6
1884	61.2	12.8	1314.8
1885	61.3	13.0	1531.7
1886	61.5	13.9	1286.3
1887	60.8	13.8	1250.0
1888	61.0	13.5	1378.5
1889	61.2	13.3	1319.3
1890	61.0	15.0	1958.2
1891	61.2	14.4	1220.8
1892	61.0	14.0	1715.1
1893	61.2	13.8	1161.3
1894	61.5	14.8	1320.8
1895	61.1	13.8	1397.8
1896	61.5	14.0	1373.9
1897	61.6	13.2	1497.2
1898	61.2	13.9	1711.9
1899	60.7	13.8	1649.1
1900	61.0	13.6	1188.0
1901	60.3	13.8	1588.9
1902	60.7	13.7	1753.7
1903	61.1	13.7	1912.2
1904	60.8	13.7	1381.8
1905	61.2	13.5	1330.1
1906	60.3	13.1	1519.5
1907	60.7	13.5	1640.4

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* With the freezing point, sea level, and gravity corrections.

The variation from year to year of the earthquake number in Tokyo seems to have no marked general relation to that of the amount of the precipitation, or to the mean temperature and barometric pressure, at the same place. The Tokyo seismic frequency varied, however, in a close parallelism with the amount of the precipitation at Niigata and Akita. As will be seen from Figs. 9 and 10, both the absolute amount of the precipitation and the general course of its variation with years were nearly alike for these two places; the annual amount of precipitation being in each case taken to be a function of the time. Fig. 8 illustrates the variation of the yearly seismic frequency in Tokyo, and of the mean amount of the precipitation at Niigata and Akita (Table VI). The curve for the seismic frequency will be observed to be, on the whole, similar to that for the precipitation (drawn in red); the highest values in both occurring in the two years 1896 and 1897. In fact the different maxima in the frequency correspond to those in the amount of the precipitation, and the two curves run nearly parallel to each other. This coincidence is probably not accidental, and the variation of the yearly number of the earthquakes felt in Tokyo may be taken to be approximately proportional to the amount of precipitation along the north-western side of the Main Island.

8. ***Weather and destructive earthquakes.*** In Japan, India, America, and probably also in some other countries, earthquakes are popularly supposed to occur specially in the so-called *earthquake weather*, namely, on sultry days. This is, however, not true, at least not generally. On the other hand, Carlyle says in his *French Revolution* : " Hope ushers in a Revolution,—as earthquakes are preceded by bright weather." Whatever may be the authority in seismological matters of the great British author, there were certainly many earthquakes which occurred in bright weather.

Indeed the relation of earthquakes to weather is a very complicated question, as it involves the considerations of the atmospheric pressure, temperature and moisture, and the precipitation. Large shocks and small shakings are often governed, in their time distribution, by entirely opposite laws. So are also earthquakes of inland origin and those of submarine origin. For the present, I shall confine myself to the consideration of some of the great destructive earthquakes in Japan, of which we have the record of the state of the accompanying weather. There were 18 of these shocks, as follows.

TABLE VIII.—RELATION TO WEATHER OF THE DESTRUCTIVE EARTHQUAKES.

No.	Date.	Time of Occurrence.	Provinces strongly shaken.	Remarks on the Weather.
1	正平十六年六月廿四日 Aug. 3, 1361.	4 am.	Kinai Provinces,* Kii, Awa. (Accompanied by *tsunami.***)	Fair (Kyoto)
2	明應七年八月廿五日 Sept. 20, 1498.	9 am.	Ise, Totomi, Mikawa, Kai, Suruga, Sagami, Izu. (Accompanied by *tsunami.*)	Do.
3	永正七年八月八日 Sept. 21, 1510.	3 am.	Settsu. The *torii*, or temple gate of Shitenno-ji, overthrown.	Do.
4	天正十三年十一月廿九日 Jan. 18, 1585.	Midnight.	Kinai Provinces, Omi, Mino, Owari, Ise, Mikawa. (Accompanied by *tsunami.*)	Snowy (Kyoto).
5	慶長元年閏七月十二日 Sept. 4, 1596.	1 am.	Yamashiro, Settsu, Izumi. (The great Keicho Earthquake, which destroyed the castle of Fushimi.)	Fair (Kyoto). Continued to be fair till 8th; rain and wind on 9th.
6	寛文二年五月一日 June 16, 1662.	11 am.	Kinai Provinces, Tanba, Wakasa, Omi, Mino, Ise, Suruga, Mikawa, Shinano. (The Kwanbun Earthquake).	In Kyoto, occasional rains from the previous evening; heavy rainfall at the time of the shock.

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* The Kinai Provinces are Yamashiro, Yamato, Kawachi, Izumi, and Settsu.

** *Tsunami* denotes the great tidal disturbances, which may be caused by submarine earthquakes, volcanic eruptions, or by barometric depressions.

TABLE VIII. *(Cont.)*

No.	Date.	Time of Occurrence.	Provinces strongly shaken.	Remarks on the Weather.
7	寛文五年十一月廿七日 Feb. 1, 1666.	5 pm.	Takata (Echigo.)	Heavy snow fall, to the amount of some 15 feet.
8	元祿十六年十一月廿三日 Dec. 31, 1703.	3 am.	Yedo (Tokyo), Sagami, Awa, Kazusa. Accompanied by *tsunami*. (The Genroku Earthquake.)	Fair in Yedo (Tokyo). Calm and clear in Kyoto.
9	寳永四年十月四日 Oct. 28, 1707.	1 pm.	Kyushu to Tokaido. (The Hoei Earthquake, the greatest of the disturbances that ever shook Japan in the historical times.)	In Kyoto, clear and calm. In Tosa (Shikoku), very clear and bright, with no cloud at all; no wind throughout the day, and warm as in summer.
10	享和二年十一月十六日 Dec. 9, 1802.	Early morning.	Ogi (province of Sado.)	On the 8th, very clear and calm.
11	文政十一年十一月十二日 Dec. 18, 1828.	7 am.	Sanjo and vicinity (province of Echigo). (The Bunsei Earthquake.)	Great snow storm in the night of the 17th, and some rain and strong winds in the morning of the 18th.
12	天保元年七月二日 Aug. 19, 1830.	4 pm.	Kyoto and the Kinai Provinces. (The Tenpo Earthquake.)	Fair on the 18th—20th; heavy rain on the 21st; fair on the 22nd and 23rd; some rain on the 24th.
13	弘化四年三月廿四日 May 8, 1847.	10 pm.	Shinano and Echigo. (The great Zenkoji Earthquake.)	Clear, calm and warm, in the day time and the evening of the 8th.
14	安政元年六月十五日 July 9, 1854.	2 am.	Kinai Provinces, Iga, Ise, Kii. (One of the Ansei Earthquakes.)	On the 8th, fair during the day time, with rain and thunder in the evening (Kyoto).
15	安政元年十一月四日 Dec. 23, 1854.	9 am.	Tokaido. (One of the Ansei Earthquakes.)	Fair in Kyoto, Kii, and the Tokaido provinces.
16	安政元年十一月五日 Dec. 24, 1854.	5 pm.	Saikaido and Nankaido. (One of the Ansei Earthquakes.)	Same fair weather as on the previous day.
17	安政二年十月二日 Nov. 11, 1855.	10 pm.	Yedo (Tokyo.)	During the day, cloudy and slightly rainy. Cleared up in the evening, the wind being unusually calm.

TABLE VIII. *(Cont.)*

No.	Date.	Time of Occurrence.	Provinces strongly shaken.	Remarks on the Weather.
18	明治廿四年十月廿八日 Oct. 28, 1891.	6.37 am.	Mino-Owari Eqke.	At Gifu, the amount of precipitation during October 1891 was unusually small, there being no rain fall at all between the 1st and 22nd of the month. Since the 23rd, there were some occasional rains, which ceased completely at about 6h 40m am. on the 28th. The sky began to clear up from about 8h 15m am. in the same morning. The great earthquake took place at 6h 37m am., while the barometer was falling.

The relation to weather of the 18 earthquakes mentioned in the above table was as follows :—

Fair or clear	weather	12	earthquakes.
Cloudy	,,	2	,,
Rainy or snowy	,,	3	,,
Rainy and windy	,,	1	,,

Thus it will be observed that 12 *out of the 18 earthquakes occurred in fair or clear weathers.* There was only one case, No. 7, in which the weather was rainy and windy. This, however, took place in Echigo, where there is during the winter months much wind and precipitation, so that it is not at all surprising that a strong earthquake should occur at Takata in a bad weather. Again, of the 18 destructive earthquakes, none occurred in a wet sultry weather, which is a contradiction to the popular belief before referred to. It is extremely probable that *great shocks do not occur in very bad weathers.*

The two great earthquakes of Hoei and Zenkoji (Nos. 9 and

13) and the Ogi earthquake (No. 10), whose dates were from Oct. 28 to May 8, took place each on a very clear, calm and warm day. It is probable that these destructive seismic disturbances happened when, after the passage of the atmospheric depressions, the whole of Japan was covered by the high pressure, so that the weather was fine and calm, and consequently warm in the day time; just in the same way as a snow storm in Tokyo is generally followed by a bright and warm day.

9. ***Earthquake weather and fires.*** None of the destructive earthquakes in Japan ever happened in the midst of a violent storm. This is a very fortunate circumstance in connection with the disastrous fires which so often break out after great shocks. Thus, on the occasion of the Yedo (Tokyo) earthquake of the 2nd year of Ansei, (No. 17), which took place at 10 pm., and which caused a loss of about 7,000 lives, fires broke out at 32 different places in the city. Owing, however, to the stillness of air, all these fires were put out before the day-break, the aggregate area of the burnt districts being about 1 square mile. This amount of the damage is much smaller than in the cases of some of the metropolitan fires, which were not connected with earthquakes. For instance, the famous Maruyama fire of the 3rd year of Meireki, on March 2, 1657, caused the loss of 107,046 lives; while the great fire of April 1, 1772, began at Meguro and reached, within 24 hours, to the Koishikawa, Shitaya, and other northern districts, reducing to ashes all the buildings within an area 24 km in length and 4 km in width. These and other gigantic fires in Yedo (Tokyo) all occurred on the occasion of great stroms, and, in the case of the Meireki catastrophe, the wind velocity is supposed to have reached 60 miles per hour. As, however, the destructive earthquakes never occurred on stormy days it is to be expected that the fires following these would not extend so enormously, provided means be properly taken for subduing the flames.*

10. ***Effects of barometric pressure and tides.*** Let us next consider the effects on the seismic frequency of the tides combined with the barometric pressure, confining our attention to the stronger or larger earthquakes, which originated in the vicinity of Tokyo or off the north-eastern coast of the Main Island. The times of the high or low waters of the tide given in the subsequent tables, relate to the tide-gauge station of Reigan-jima, Tokyo, and are practically identical to those for Yokohama. The tidal movements along the north-eastern coast of the Main Island take place some half an hour earlier than those at Tokyo and Yokohama.

11. ***Stronger earthquakes originating from the Izu island zone.*** Table IX is a list of the 14 recent stronger submarine earthquakes, which originated along the Fuji volcanic chain, namely, from among the Izu islands or in the vicinity of Hachijo, Ogasawara (Bonin), and other islands some distance off the coast of Izu peninsula; the moment of the high or low water at Reigan-jima (Tokyo) nearest to the time of occurrence of each earthquake being also given for the sake of comparison.

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* §§ 8 and 9 are translations of my notes in Japanese published in the "Toyo Gakugei Zasshi," Dec. 1906.

TABLE IX.—LIST OF THE RECENT STRONGER SUBMARINE EARTHQUAKES WHICH ORIGINATED ALONG THE FUJI VOLCANIC CHAIN.

(i) Date.	(ii) Time of Eqke. Occurrence.	(iii) Time of High or Low water at Reigan-jima (Tokyo).		Time Difference (ii)-(iii).
April 16, 1890.	9^h 30^m pm.	9^h 18^m pm.	Low water.	0^h 12^m
Feb. 12, 1896.	6 38 am.	4 43 am.	High water.	1 55
May 7, ,,	2 37 pm.	1 51 pm.	,,	0 46
Jan. 18, 1897.	9 27 ,,	0 38 am. (next day).	Low water.	—
March 27, 1898.	3 24 am.	2 59 am.	,,	0 25
Jan. 31, 1900.	2 38 ,,	0 23 ,,	,,	2 15
Nov. 5, ,,	4 41 pm.	3 45 pm.	High water.	0 56
,, 9, ,,	2 55 am.	1 29 am.	Low water.	1 26
,, 19, ,,	10 59 pm.	10 30 pm.	,,	0 29
Feb. 20, 1902.	10 50 am.	10 44 am.	,,	0 06
June 3, 1903.	0 28 pm.	11 36 ,,	High water.	0 52
Nov. 13, 1904.	9 49 am.	8 55 ,,	,,	0 54
June 7, 1905.	2 40 pm.	3 03 pm.	Low water.	−0 23
May 4, 1907.	5 37 ,,	4 43 ,,	,,	0 54

With regard to the diurnal variation of the barometric pressure, the times of the earthquakes tabulated above may be grouped, except the 2nd and the last, as follows:—

(*A*).....	9 30^{m} pm. 9 27 „ 10 50 „	(*C*).....	$2^{h}\ 37^{m}$ pm. 4 41 „ 0 28 „ 2 40 „
(*B*).....	10 50 am. 9 49 „	(*D*).....	3 24 am. 2 38 „ 2 55 „

The two groups *A* and *B* occurred at the hours of the barometric maximum, while the two other groups *C* and *D* occurred at the hours of the barometric minimum.

The difference between the time of earthquake occurrence and the nearest moment of the high or low water of the tide varied, except in the case of the 4th earthquake, between 0h 12m and 2h 15m, giving the average value of 50m. This is to be regarded as the interval by which the different earthquakes followed, except in one case, the high or low water in the Tokyo Bay, which happens not much apart in time from that along the islands of the zone in question.

12. ***Recent strong earthquakes felt in Tokyo.*** In § 8 I have considered some of the great destructive earthquakes in Japan in relation to weather. Turning now our attention to the recent earthquakes felt in Tokyo, we have 14 cases, in which the motion was strong or severe; amongst others, the shock (No. 7) of June 20, 1894, was semi-destructive and caused a considerable amount of damage. The relation of their times of occurrence to the low or high water epoch of the tide and the barometric pressure is shown in the following table.

TABLE X.—LIST OF STRONG EARTHQUAKES FELT IN TOKYO.

(h)....High water ; (l)....Low water.

No.	Date.	Time of Earthquake Occurrence.	Time of High or Low Water at Reigan-jima, Tokyo Bay.	Barometric Pressure. (With sea-level and freezing point corrections).
1	Feb. 22, 1880.	$0^{h}\ 49^{m}$ am.	$2^{h}\ 08^{m}$ am. (h)	**Min.** 754.6 mm. Pressure rose after the shock.
2	Oct. 15, 1884.	4 21 am.	2 00 am. (h)	**Min.** 754 mm, at 4 pm., on 14th.
3*	Jan. 15, 1887.	6 51 pm.	9 48 pm. (h) 3 36 pm. (l)	**Min.** 754 mm, at 2 am., on 15th.
4*	April 29, 1888.	10 00 am.	7 13 am. (h) 1 25 pm. (l)	Bar. height = 759 mm. pressure decreasing.
5	Feb. 18, 1889.	6 09 am.	7 04 am. (h)	**Min.** 746 mm, at 2 pm., on 17th.
6*	Dec. 24, 1891.	5 30 am.	5 07 am. (l)	Bar. height = 762 mm, pressure increasing.
7*	June 20, 1894.	2 04 pm.	0 42 pm. (l)	**Min.** 754.7 mm. at 3–8 pm., on 20th.
8	Jan. 18, 1895.	10 48 pm.	10 49 pm. (h)	**Min.** Mean pressure on 18th = 752.6 mm.
9	April 23, 1901.	3 10 am.	3 23 am. (l)	On 23rd, Min. 757 mm. at 4 am., Pressure increasing
10	June 23, 1902.	7 13 am.	6 31 am. (h)	**Min.** 741.5 mm, at 7 am, on 24th.
11	Feb. 24, 1906.	9 14 am.	6 57 am. (h)	Mean pressure on 24th = 759 mm. Barometer ascending.
12	June 11, 1907.	8 59 am.	4 29 am. (h) 1 16 pm. (l)	**Min.** 746 mm, at 10 pm., on 13th.
13	Sept. 22, 1907.	4 50 am.	5 27 am. (h)	Pressure in the normal condition. Bar. height = 756 mm at 6 am., on 22nd.
14*	Nov. 22, 1907.	2 17 am.	2 06 am. (l)	**Max.** 774 mm, at 6 am., on 22nd.

* Earthquakes of inland origin.

With regards to the atmospheric pressure, it is a notable fact that 8 out of the 14 earthquakes were accompanied by the marked depression of 741.5 to 754.7 mm. and one by a very high pressure of 774 mm; there being only 5 earthquakes which occurred when the pressure was in the normal condition, between 756 and 762 mm. Of the 8 cases of barometric minima above noted, 4 preceded, 2 followed, and 2 were nearly simultaneous with the respective earthquakes. These relations to the atmospheric pressure of the strong and severe shocks need not necessarily be similar to those in the case of the great destructive earthquakes (§ 8).

The difference between the time of earthquake occurrence and that of the corresponding high or low water of the tide varied in 11 out of the 14 cases, between 0h 0m and 2h 21m; only in the 3 remaining cases, earthquakes happened midway between the high and low waters. Again, of the 8 earthquakes accompanied by barometric depressions, six were of submarine origin, and five of these occurred near the time of the high waters. On the other hand, of the 5 earthquakes of inland origin, three occurred with the low water and two between the low and high waters.

13. ***List of the stronger earthquakes whose origins were not much distant from Tokyo.*** The two tables XI and XII give a list of the 145 stronger earthquakes, which happened between 1902 and 1907, and whose origins were mostly in the Kwanto provinces* or off their coasts not much distant from Tokyo. The land area of disturbance of each of these earthquakes, including that in which the motion was insensible but was recorded by the ordinary Gray-Milne-Ewing type seismographs, was greater than 1,000 square *ri*. (See also the *Bulletin*, Vol. II, No. 1.) The time of the low or high water in the Tokyo Bay nearest to that of each of the earthquakes is given in the 4th column of the two tables. The different earthquakes are divided into ten groups according to the positions of their origins.

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* The Kwanto provinces are Sagami, Musashi, Awa, Kazusa, Shimosa, Hitachi, etc.

TABLE XI.—STRONGER EARTHQUAKES WHOSE CENTRES WERE NOT MUCH DISTANT FROM TOKYO. INLAND ORIGIN.

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference (i)-(ii).
Group I. Musashi (eastern part excepted.)	Dec. 9, 1902	1^{h} 53^{m} am.	$5^{h}00^{m}$ am. (l) 11 02 pm. (h) (preceding day).	h m —
	March 13, 1903	3 04 pm.	5 23 pm. (h)	−2 19
	April 24, 1905	5 15 am.	3 33 am. (l)	1 42
	May 30, „	4 32 am.	2 33 am. (h)	1 59
	May 10, 1906	2 34 pm.	1 54 pm. (l)	0 40
	July 27, 1907	4 23 pm.	1 55 pm. (l)	2 28
	Nov. 10, „	2 03 am.	3 12 am. (l)	−1 09
	„ 22, „	2 17 am.	2 06 am. (l)	0 11
Group II. Sagami.	Jan. 17, 1902	4 18 am.	4 59 am. (l)	−0 41
	April 1, „	5 32 am.	5 03 am. (l)	0 29
	July 1, „	2 01 am.	0 40 am. (h)	1 21
	Sept. 16, „	3 19 am.	4 09 am. (h)	−0 50
	July 9, 1903	3 00 pm.	0 11 pm. (l) 5 14 pm. (h)	—
	Jan. 15, 1906	7 55 am.	8 49 am. (h)	−0 54
Group III. Western part of Hitachi, and Shimotsuke.	March 3, 1902	2 35 pm.	0 36 pm. (l)	1 59
	June 20, „	5 49 pm.	4 58 pm. (h)	0 51
	Nov. 5, „	5 49 pm.	3 00 pm. (l) 8 08 pm. (h)	—
	March 13, 1903	1 11 pm.	0 21 pm. (l)	0 50
	July 6, „	3 19 am.	2 42 am. (h)	0 37
	„ 15, „	4 51 am.	3 16 am. (l)	1 35
	„ 21, „	2 06 pm.	2 24 pm. (h)	−0 18
	April 27, 1904	3 14 am.	3 00 am. (h)	0 14
	Sept. 17, 1906	5 27 pm.	5 18 pm. (h)	0 09
	April 18, 1907	2 33 am.	2 23 am. (l)	0 10
Group IV. Kai.	May 25, 1902	8 29 pm.	7 02 pm. (h)	1 27
	Feb. 3, 1903	4 59 am.	3 27 am. (l)	1 32

TABLE XI. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference (i)–(ii).
Group V. Shimosa, vicinity of Kasumiga-ura (Hitachi), Kazusa, eastern part of Musashi.	March 3, 1902	9^h 13^m am.	$11^h 13^m$ am. (h)	$-2^h 00^m$
	" 25, "	2 35 pm.	1 09 pm. (l)	1 26
	May 15, "	7 38 am.	5 57 am. (l)	1 41
	Aug. 8, "	8 37 am.	8 05 am. (h)	0 32
	Dec. 14, "	1 57 pm.	4 35 pm. (h)	−2 38
	" 31, "	2 38 pm.	1 14 pm. (l)	1 24
	Jan. 5, 1903	8 44 am.	9 00 am. (h)	−0 16
	March 12, "	5 35 am.	4 23 am. (h)	1 12
	April 22, "	5 02 am.	7 55 am. (l)	−2 53
	May 6, "	8 52 am.	7 27 am. (l)	1 25
	June 7, "	8 38 am.	10 11 am. (l)	−1 33
	Dec. 9, "	8 55 am.	8 30 am. (h)	0 25
	March 12, 1904	6 12 am.	8 51 am. (l)	−2 39
	April 4, "	8 20 am.	7 49 am. (h)	0 31
	May 8, "	7 24 am.	6 03 am. (l)	1 21
	June 30, "	8 21 am.	6 43 am. (h)	1 38
	Aug. 4, "	9 49 pm.	10 34 pm. (h)	−0 45
	Oct. 5, "	0 35 am.	1 24 am. (h)	−0 49
	April 6, 1905	9 30 pm.	6 16 pm. (h) 1 31 am. (l) (next day).	——
	May 30, "	4 32 am.	2 33 am. (h)	1 59
	June 11, "	11 51 pm.	0 12 am. (h) (next day).	−0 21
	Sept. 21, "	10 00 pm.	10 05 pm. (h)	−0 05
	" 24, "	2 08 am.	0 50 am. (h)	1 18
	Oct. 19, "	9 10 am.	8 18 am. (h)	0 52
	Jan. 9, 1906	5 51 pm.	3 39 pm. (h) 0 42 am. (l) (next day).	——
	Feb. 18, "	2 15 pm.	11 22 am. (h)	2 53
	May 21, "	3 56 pm.	4 57 pm. (h)	−1 01
	" 29, "	11 22 pm.	10 11 pm. (h)	1 11

TABLE XI. (*Cont.*)

Origin of Eqke	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group V. Shimosa, Vicinity of Kasumiga-ura (Hitachi), Kazusa, eastern part of Musashi. (*Cont.*)	Aug. 21, 1906	5^{h} 42^{m} am.	$5^{h}23^{m}$ am. (h)	0^{h} 19^{m}
	" 22, "	0 08 am.	1 13 am. (l)	−1 05
	Oct. 6, "	6 35 pm.	6 43 pm. (h)	−0 08
	Nov. 12, "	11 07 pm.	10 03 pm. (l)	1 04
	Dec. 24, "	5 46 pm.	8 06 pm. (l)	−2 20
	Jan. 3, 1907	3 42 am.	2 39 am. (l)	1 03
	Feb. 22, "	9 57 pm.	8 02 pm. (l)	1 55
	March 13, "	0 38 am.	11 53 pm. (l) (preceding day)	0 45
	July 2, "	5 45 am.	4 32 am. (l)	1 13
	Nov. 28, "	11 28 am.	0 01 pm. (h)	−0 33
	Dec. 11, "	5 54 pm.	4 11 pm. (l)	1 43

TABLE XII.—STRONGER EARTHQUAKES WHOSE CENTRES WERE NOT MUCH DISTANT FROM TOKYO. SUBMARINE ORIGIN.

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group VI. Off the coast of Hitachi.	May 17, 1902	1^{h} 18^{m} pm.	$1^{h}50^{m}$ pm. (h)	-0^{h} 32^{m}
	Oct. 16, "	1 57 am.	4 16 am. (h)	−2 19
	Feb. 13, 1903	0 45 pm.	1 28 pm. (l)	−0 43
	July 1, "	9 10 am.	10 03 am. (h)	−0 53
	Dec. 18, "	11 20 am.	11 54 am. (l)	−0 34
	March 8, 1904	3 40 am.	4 31 am. (l)	−0 51
	Oct. 2, 1905	10 54 am.	7 26 am. (h) 2 42 pm. (l)	——
	Dec. 26, "	0 11 pm.	0 22 pm. (l)	−0 11
	Jan. 25, 1907	6 35 pm.	10 12 pm. (l) 1 02 pm. (h)	
	April 30, "	0 51 pm.	2 05 pm. (l)	−1 14
	May 5, "	2 16 am.	4 51 am. (l)	−2 35
	Oct. 15, "	9 05 am.	6 02 am. (l) 1 54 pm. (h)	——

TABLE XII. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group VII. Off the coast of Shimosa.	Nov. 13, 1902	8^h 15^m am.	$10^h 06^m$ am. (l)	-1^h 51^m
	Oct. 27, 1904	6 24 am.	6 37 am. (h)	−0 13
	Dec. 12, „	9 56 am.	5 29 am. (h) 0 46 pm. (l)	——
	Oct. 10, 1905	10 54 am.	10 21 am. (l)	0 33
	Nov. 2, „	11 21 am.	8 45 am. (h)	2 36
	May 18, 1906	9 36 pm.	9 03 pm. (l)	0 33
	„ 19, „	1 31 am.	2 41 am. (h)	−1 10
Group VIII. Off the E. coast of Awa-Kazusa Peninsula.	July 26, 1902	7 51 am.	8 39 am. (h)	−0 48
	Jan. 31, 1903	1 47 am.	1 47 am. (l)	0 00
	March 26, „	0 59 am.	3 37 am. (h)	−2 38
	April 19, „	7 48 pm.	5 02 pm. (l) 10 36 pm. (h)	——
	July 12, 1904	7 40 pm.	4 46 pm. (h)	2 54
	„ 15, „	3 44 am.	1 39 am. (l)	2 05
	„ 16, „	10 09 am.	7 26 am. (h)	2 43
	„ 17, „	4 27 am.	3 08 am. (l)	1 19
	„ 18, „	7 51 pm.	9 29 pm. (h)	−1 38
	„ 19, „	6 20 pm.	5 03 pm. (l)	1 17
	„ 20, „	0 30 pm.	10 58 am. (h)	1 32
	Feb. 17, 1906	6 41 am.	4 20 am. (l) 9 52 am. (h)	——
	„ 23, „	6 49 pm.	5 13 pm. (h)	1 36
	„ 24, „	9 14 am.	6 50 am. (h)	2 24
	March 6, „	1 38 am.	2 48 am. (h)	−1 10
	„ 14, „	8 32 pm.	8 13 pm. (h)	0 19
	April 8, „	2 52 pm.	0 41 pm. (l)	2 11
	May 7, „	8 01 am.	3 55 am. (h) 11 27 am. (l)	——
	„ 28, „	6 59 am.	6 45 am. (h)	0 14
	Sept. 9, „	3 53 am.	3 23 am. (l)	0 30
	Oct. 19, „	9 23 pm.	5 31 pm. (h) 1 45 am. (l)	——

TABLE XII. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group VIII. Off the coast of Awa-Kazusa Peninsula. *(Cont.)*	Nov. 11, 1906	0^{h} 33^{m} am.	11^{h}28^{m} pm. (h) (preceding day).	1^{h} 05^{m}
	„ 23, „	3 32 pm.	5 52 pm. (l)	−2 20
	Jan. 25, 1907	0 33 am.	3 26 am. (h)	−2 53
	Feb. 6, „	5 38 pm.	5 18 pm. (l)	0 20
	June 11, „	8 59 am.	4 29 am. (h) 1 16 pm. (l)	——
	„ 14, „	1 43 pm.	2 38 pm. (l)	−0 55
	Sept. 22, „	4 50 am.	5 27 am. (h)	−0 37
Group IX. Off the coast of Sagami, and outside the Tokyo Bay.	Apri 18, 1904	8 03 pm.	6 57 pm. (h)	1 06
	Jan. 8, 1906	11 00 pm.	11 50 pm. (l)	−0 50
	Nov. 7, „	11 54 pm.	6 46 pm. (h) 4 16 am. (l) (next day)	——
	Oct. 13, 1907	1 46 pm.	2 35 pm. (l)	−0 49
Group X. Tokyo Bay, and Uraga Channel.	March 12, 1902	10 48 am.	1 53 pm. (l) 6 36 am. (h)	——
	April 5, „	7 23 pm.	10 16 pm. (l)	−2 53
	„ 6, „	2 13 am.	3 30 am. (h)	−1 17
	June 23, „	7 42 am.	6 31 am. (h)	1 11
	Aug. 7, „	0 36 pm.	2 40 pm. (l)	−2 04
	Oct. 12, „	10 24 am.	7 41 am. (l) 1 38 pm. (h)	——
	Aug. 23, 1903	9 33 pm.	5 47 pm. (h) 1 05 am. (l)	——
	Oct. 27, „	9 57 pm.	9 47 pm. (h)	0 10
	Nov. 6, „	7 04 pm.	5 53 pm. (h)	1 11
	„ 10, „	6 51 pm.	3 51 pm. (l) 9 04 pm. (h)	——
	Feb. 26, 1904	5 50 pm.	7 39 pm. (l)	−1 49
	May 17, „	4 03 pm.	1 35 pm. (l)	2 28
	„ 27, „	5 41 am.	3 28 am. (h)	2 13
	„ „ „	7 46 am.	10 36 am. (l)	−2 50
	March 4, 1905	9 18 pm.	11 53 pm. (l)	−2 35
	„ 6, „	6 08 am.	5 26 am. (h)	0 42

TABLE XII. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii).
Group X. Tokyo Bay, and Uraga Channel. *(Cont.)*	July 19, 1905	5^h 03^m pm.	7^{h}11^m pm. (h)	−2^h 08^m
	Aug. 12, „	9 28 pm.	10 35 pm. (l)	−1 07
	Sept. 3, „	2 02 am.	2 42 am. (l)	−0 40
	Oct. 14, „	11 54 am.	0 44 pm. (l)	−0 50
	Dec. 30, „	7 53 pm.	8 24 pm. (h)	−0 31
	Jan. 9, 1906	9 56 pm.	0 42 am. (l) (next day)	−2 46
	May 21, „	2 21 pm.	4 57 pm. (h)	−2 36
	„ 24, „	2 17 pm.	1 33 pm. (l)	0 44
	„ 30, „	9 27 pm.	11 02 pm. (h)	−1 35
	Aug. 5, „	4 53 am.	5 02 am. (h)	−0 09
	„ „ „	5 32 am.	„	0 30
	Oct. 1, 1907	6 16 pm.	7 18 pm. (l)	−1 02
	Nov. 21, „	1 32 pm.	0 33 pm. (l)	0 59

Earthquakes of Inland Origin, Groups I to IV. Groups I to IV, Table XI, include the 26 earthquakes which originated, in the regions adjacent to the plain of the lower course of the Tone-*gawa* and its tributaries, namely, in the provinces of Musashi (eastern part excepted), Sagami, western part of Hitachi, Shimotsuke, and Kai. A striking feature in the diurnal distribution of these inland earthquakes is that, with the exception of the two, which occurred between 7 and 9 pm., they have all taken place between 1 and 6 am. and 1 and 6 pm., namely, at those hours when the barometric pressure is maximum. (See also Table XIII.)

The relation of the 26 earthquakes to the phases of the tide, was as follows :—

(*a*) 11 occurred with the high tide ;

(*b*) 12 occurred with the low tide;
(*c*) 3 „ between the high and low tides.

Again of the earthquakes of (*a*) and (*b*), 17 occurred after, and 6 occurred before, the low or high water. Taking the average from the cases of these 23 earthquakes, the latter followed the high or low water by a mean interval of 31 minutes.

Earthquakes of Inland Origin, Group V. The earthquakes of Group V originated in the extensive quarternary tracts, which comprise the province of Shimosa, the vicinity of the Kasumiga-ura (Hitachi), the eastern part of the province of Musashi, and a portion of Kazusa. The positions of the origins of some of these earthquakes, all inferred from the area of disturbance and the isoseismal lines, are uncertain, and were possibly off the Pacific coast of the Awa-Kazusa peninsula.

In the diurnal distribution, the earthquakes of Group V do not show the same characteristic as those of Groups I to IV, but are similar to the submarine disturbances of Groups VI to X. Out of the 39 earthquakes, 21 occurred with the high water, 15 with the low water, and the remaining 2 between the high and low waters. Again, 23 of these earthquakes took place *before*, and 15 *after*, the high or low water.

Earthquakes of Submarine Origin. The 80 earthquakes of Groups VI to X originated off the Pacific coasts of the provinces of Hitachi, Shimosa, and Sagami, and of the Awa-Kazusa peninsula, or in the Tokyo Bay. The following table gives the hourly frequency of these earthquakes taken conjointly with those of Group V, as well as that of the inland shocks, Groups I to IV.

TABLE XIII.—DIURNAL VARIATION OF THE EARTHQUAKES OF GROUPS I to X.

Hour.	A.M.				P.M.			
	(a) Eqkes of Groups I to IV. (Inland Origin.)		(b) Eqkes of Groups V to X.		(a) Eqkes of Groups I to IV. (Inland Origin.)		(b) Eqkes of Groups V to X.	
0—1	0	**14**	6	**28**	0	**10**	5	**24**
1—2	1		4		1		5	
2—3	4		4		3		6	
3—4	3		4		2		2	
4—5	4		4		1		1	
5—6	2		6		3		5	
6—7	0	**1**	5	**35**	0	**1**	7	**32**
7—8	1		5		0		6	
8—9	0		10		1		2	
9—10	0		6		0		11	
10—11	0		5		0		1	
11—12	0		4		0		5	

As will be seen from the above table, the earthquakes of the submarine and coast origins, namely, those of Groups V to X, show a tendency of occurring more frequently between 6 and 12 am., and between 6 and 12 pm., than during the earlier hours both in the forenoon and afternoon. This is approximately the reverse of the order of occurrence of the maxima in the diurnal variation of the earthquakes of inland origin, Groups I to IV.

Of the 80 submarine earthquakes of Groups VI to X, 33 each occurred with the high and low waters, while the remaining 14 occurred between these two phases of the tide. Again, 29 of the earthquakes occurred *after*, and 38 *before*, the times of the high or low water.

TABLE XIV.—SIX-HOURLY DISTRIBUTION OF THE EARTHQUAKES.

Origin.	0–6 A.M. and 0–6 P.M.			6–12 A.M. and 6–12 P.M.		
	With High Water.	With Low Water.	Between High and Low Waters.	With High Water.	With Low Water.	Between High and Low Waters.
Inland. Groups I-IV.	9	12	3	2	0	0
Shimosa, etc. Group V.	9	8	0	12	7	2
Submarine. Groups VI-X.	15	20	0	18	13	14

From Table XIV, it will be observed that the 16 submarine and coast earthquakes of Groups V–X, whose times of occurrence were between those of the high and low waters of the tide, happened exclusively between 6 and 12 am. and between 6 and 12 pm., namely, as follows :—

6^h 35^m pm.	9^h 29^m pm.
6 41 am.	9 30 pm.
6 51 pm.	9 33 pm.
6 51 pm.	9 59 am.
7 48 pm.	10 24 am.
8 01 am.	10 48 am.
8 59 am.	10 54 am.
9 05 am.	11 54 pm.

Taking the average of these times of occurrence, irrespective of their being antemeridian or postmeridian, we obtain the value of 8h 58m, or about 9h am. and 9h pm. These hours, which correspond to those of the barometric maxima in the diurnal variation, may be taken as giving the probable time when a strong earthquake, in the region under consideration, is to take place intermediate between the high and low water epochs.

Diurnal Variation of the Seismic Frequency in relation to the Phases of the Tide. Table XV gives the diurnal variations of the earthquakes occurring with the high water and the low water, and between these two, the Groups I to X being taken together.

TABLE XV.—DIURNAL VARIATION OF THE SEISMIC FREQUENCY IN RELATION TO THE PHASES OF THE TIDE.

Hour.	Earthquakes occurring					
	with High Water.		with Low Water.		between High and Low Waters.	
0—1 A.M.	4	**20**	2	**20**	0	**1**
1—2	3		1		1	
2—3	3		5		0	
3—4	3		4		0	
4—5	3		4		0	
5—6	4		4		0	
6—7 A.M.	3	**18**	1	**11**	1	**8**
7—8	3		3		1	
8—9	5		3		2	
9—10	4		0		2	
10—11	1		2		2	
11—12	2		2		0	
0—1 P.M.	1	**11**	4	**21**	0	**2**
1—2	2		4		0	
2—3	3		6		1	
3—4	2		1		0	
4—5	0		2		0	
5—6	3		4		1	
6—7 P.M.	2	**15**	2	**10**	3	**8**
7—8	4		1		1	
8—9	3		0		0	
9—10	4		5		3	
10—11	0		1		0	
11—12	2		1		1	
Sum.	**64**		**62**		**19**	

Thus the earthquakes corresponding to the low water occurred twice as frequently between 0 and 6 am. and between 0 and 6 pm., as during the remaining hours. On the other hand, the earthquakes corresponding to the high water and the middle of the high and low waters, occurred not less or more frequently between 6 and 12 am. and between 6 and 12 pm., than during the other hours. It thus seems that, on the whole, the moderate earthquakes shaking the vicinity of Tokyo tend to occur more frequently with the minimum barometric pressure and the low tide, as well as with the maximum barometric pressure and the high tide. This is in accordance with one of the principles explained in § 4.

14. ***Conclusion.*** The results obtained in the foregoing §§, which are only fragmentary notes on the secondary seismic causes, show nevertheless that these latter play a very important part in the distribution of earthquakes during the day, the year, the lunar day, etc. As these secondary causes probably determine the ultimate moment when a long-continued underground stress gives rise to a sudden disturbances, their careful study will be, in conjunction with the observation on the *fore-shocks* (see the preceding article), and the investigation on *earthquake zones*, of help in approximately predicting under favorable circumstances the earthquakes likely to happen in a given district. For an illustrative example in this connection, I may refer the reader to my preliminary note on the Formosa earthquake of March 17, 1906 (the *Bulletin*, Vol. I, No. 2). The periodicity of earthquakes, other than the diurnal and the annual, also probably depends to a great extent on the secondary causes.

On the Destructive Earthquakes in the Shinano-gawa Valley and those along the Japan Sea Coast.

By

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Member of the Imperial Earthquake Investigation Committee.

With Pls. XXIX-XXXI.

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§ 1. Earthquakes in the Shinano-*gawa* Valley.
§ 2. Zenkoji Earthquake of 1847.
§ 3. Sanjo (Echigo) Earthquake.
§ 4. Uzen and Sado Earthquake.
§ 5. Relation of Zenkoji Earthquake to the two others.
§ 6. Relation between the former destructive and the recent strong earthquakes in the Shinano-*gawa* Valley.
§ 7. Destructive earthquakes along the Japan Sea coast.

1. ***Earthquakes in the Shinano-gawa valley.*** The Zenkoji earthquake of 1847 and the Sanjo earthquake of 1828 were two great historical shocks which occurred in the Shinano-*gawa* valley. I give next a short account of these disturbances and also of the Sado-Uzen earthquake of 1833, whose origin was in the Japan Sea.

2. ***Zenkoji earthquake of 1847.*** (See Fig. 1.) The great disturbance in the 4th year of Koka, generally known as the Zenkoji Earthquake, took place on May 8, 1847, at about 9 pm., and was one of the most violent shocks which ever occurred in Japan, the total number of the killed being not less than 8,600. The region of destructive motion of the earthquake, which shook strongly the northern part of the province of Shinano, and a portion of the province of Echigo, stretched from a place some

5 km to the east of the city of Takata, on the north, to the vicinity of the town of Matsumoto, on the south. The area, which was about 2,100 sq. km, with an average width of about 32 km, run in a SWS-NEN direction for a distance of 110 km, along the main course of the Shinano-*gawa* and its tributary, the Sai-*gawa*. On the south-east, it extended along the Chikuma-*gawa*, another tributary of the Shinano-*gawa*, to the vicinity of the town of Ueda; while, on the north-east, it reached almost to the boundary of the province of Shinano and the Naka-Uonuma and Higashi-Kubiki counties of Echigo.

The protuberance of the area in question on the north was probably due to the softness of the alluvial formation of the plain of Takata. The damage was, on the other hand, comparatively light in the mountainous region between Matsumoto and Ueda, partly on account of the scarcity of population.

The region, within which the greatest amount of damage was done, was about 480 sq. km in area, with an average width of 10 km, and extended for a distance of about 50 km from the vicinity of Iiyama on the north-east, to Shinmachi on the south-west, also branching out to the town of Inariyama on the south. This area, which was situated almost entirely on the west side of the Shinano-*gawa* and Sai-*gawa*, was made up mostly of tertiary and volcanic formations, and included amongst others, the following towns and villages:—

Nagano	Almost entirely destroyed.
Inariyama	500 people killed.
Shiosaki-mura.	1,400 (out of 1,600) houses destroyed.
Mure.	Almost entirely destroyed.
O-koma.	Do.
Nojiri.	83 houses destroyed.

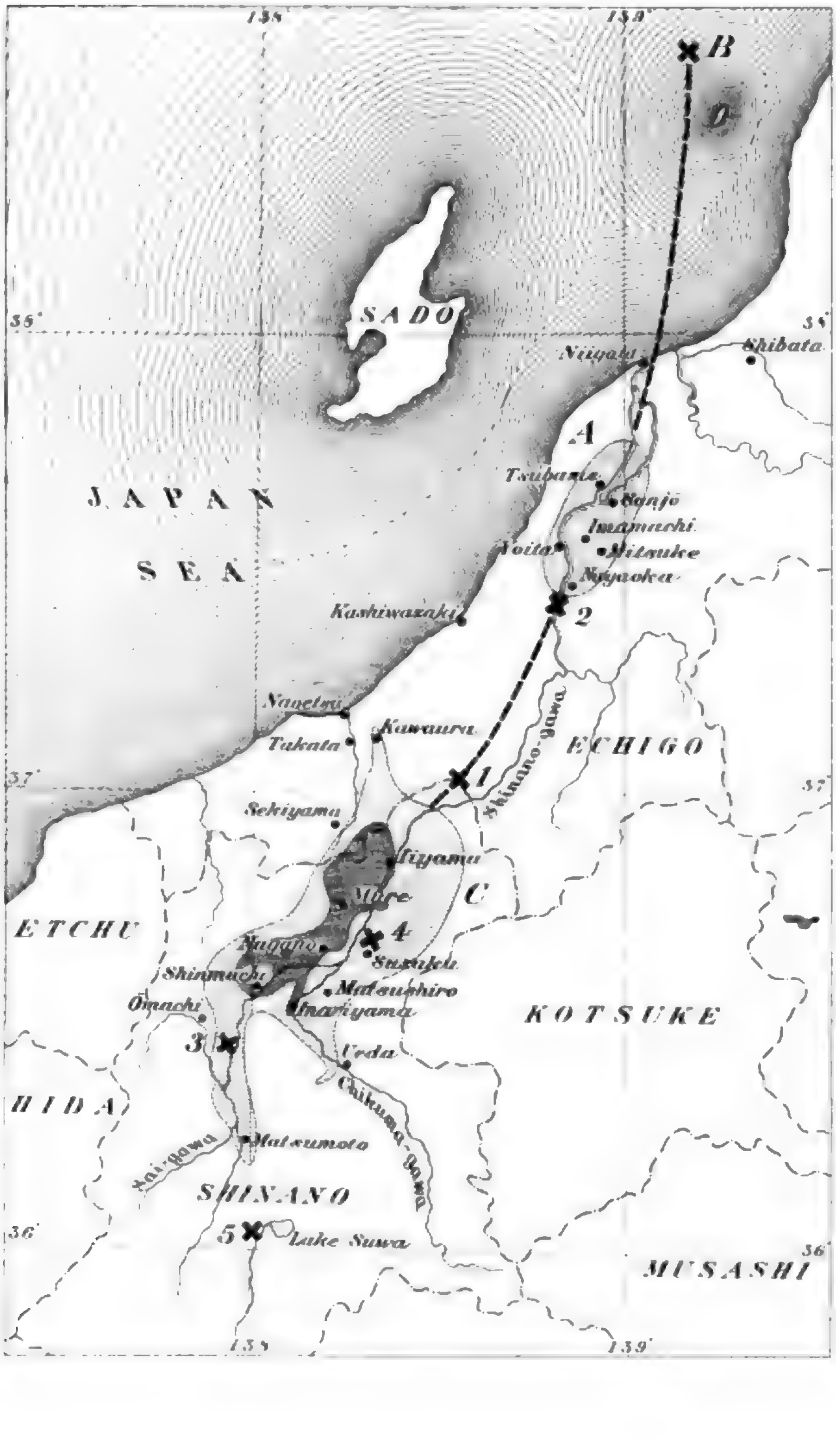
The central axis of the area of the greatest damage extended from a little west of Iiyama, through the vicinity of Mure, to the valley tract of the Sai-*gawa* at some distance to the south-west of Nagano.

The city of Nagano suffered very severely, and was almost entirely destroyed by the shock and the subsequent fires; the number of the houses overthrown being, in the town or business quarters alone, 2350, of which 2194 were burnt. In Nagano and the suburbs, there were altogether 2,452 houses destroyed by fire, there being only 191 houses which escaped both shock and flame. The number of the killed, which could be ascertained, was about 2,400; this heavy amount of casualty being, in a great measure, due to the fact that the disastrous earthquake took place when multitude of people from different parts of the country were staying at Nagano, to attend the religious festivals held at the Zenkoji. The latter, which is one of the most sacred Buddhist temples in Japan, received no material damage from the earthquake, although the huge wooden structure must have been shaken tremendously, as was indicated by the throwing down of a heavy bronze bell, about 2.6 feet in diameter and 3.6 feet in height, hung in the front verandah. Fig. 3 shows the lower portion of the bell and the scar made on the corner post by the impact of the latter; while Fig. 2 gives a front view of the temple, which is in the same condition as before the great earthquake of 1847. Both of these pictures have been taken in 1908.

A special feature of the Zenkoji earthquake was the occurrence, among the mountains of tertiary formations, of landslips whose number was not less than 44,000. Amongst others, the southern side of Mount Iwakura, which is on the Sai-*gawa*, at a distance of about 12 km to the WSW of Nagano, was destroyed,

Fig. 1. Map showing the Areas of Destructive Motion of the Zenkoji and Sanjo Earthquakes.

A . . . Sanjo Earthquake of 1828. (Area of destructive motion).
B . . . . Uzen and Sado Earthquake of 1833.
C . . . . Zenkoji Earthquake of 1847. (The lightly shaded part indicates the area of destructive motion, and the densely shaded part the area of the greatest violence.)


138
139
B
38°
SADO
38°
Niigata
Shibata
A
JAPAN
SEA
Tsubame
Sanjo
Imamachi
Yoita
Mitsuke
Nagaoka
Kashiwazaki
2
Naoetsu
Kawaura
Takata
ECHIGO
Shinano-gawa
1
37°
37°
Sekiyama
Iiyama
Mure
C
ETCHU
Nagano
4
Suzaka
Shinmachi
Matsushiro
Omachi
Inariyama
KOTSUKE
3
Ueda
HIDA
Chikuma-gawa
Sai-gawa
Matsumoto
SHINANO
36°
5
Lake Suwa
36°
MUSASHI
138
139°

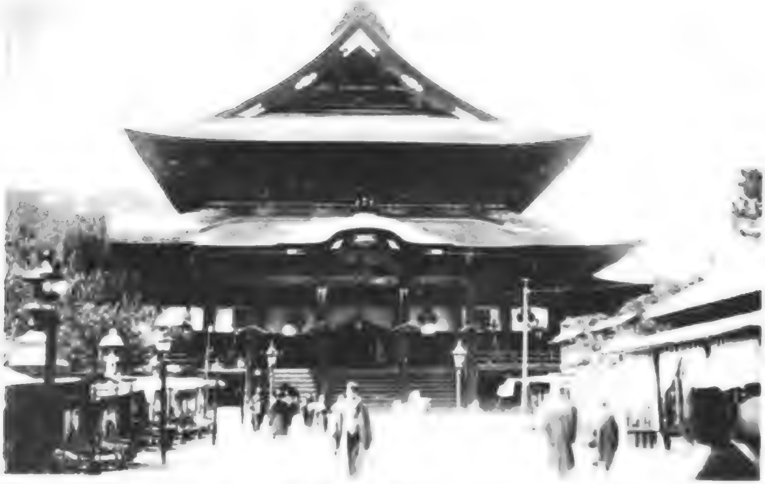


Fig. 2. The Zenkoji Temple. Front view.

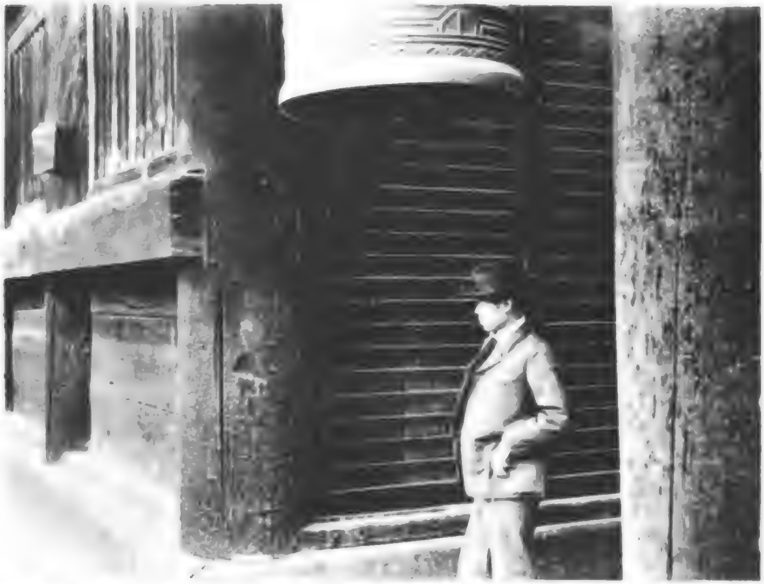
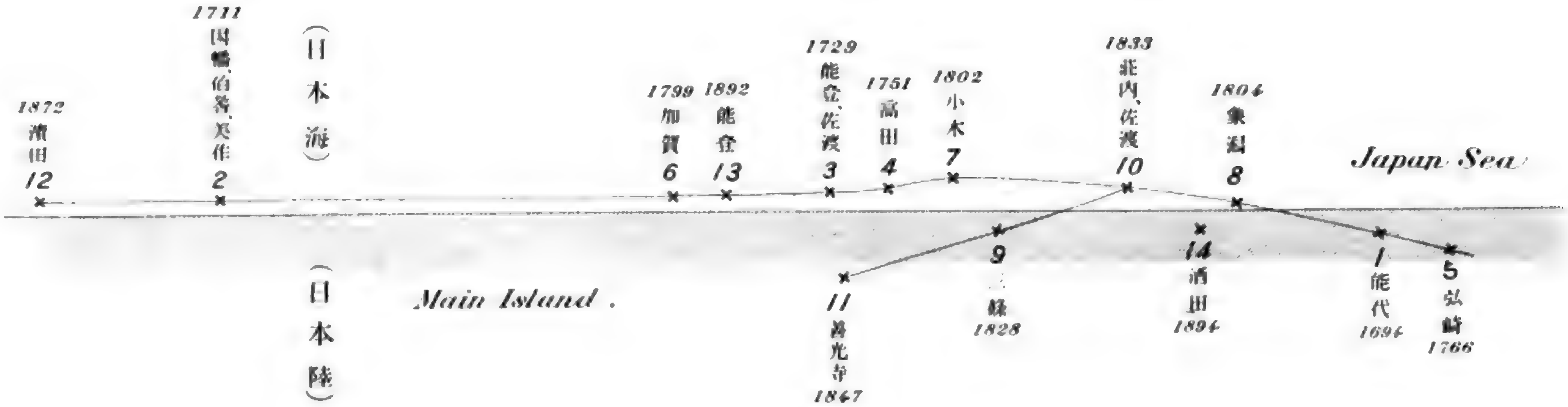


Fig. 3. The Zenkoji Temple, showing the scar (indicated by a small cross ×) made on the corner post by the bell thrown down on the occasion of the earthquake of 1847.

Fig. 4. Diagram indicating the Positions of the Destructive Earthquakes in the Shinano-*gawa* Valley and along the Japan Sea Coast.


1872
濱田
12
1711
因幡, 伯耆, 美作
2
（日本海）
（日本陸）
Main Island.
1799
加賀
6
1892
能登
13
1729
能登, 佐渡
3
1751
高田
4
1802
小木
7
1833
庄内, 佐渡
10
1804
象潟
8
Japan Sea
11
善光寺
1847
9
三條
1828
14
酒田
1894
1
能代
1694
5
弘前
1766

1.... Noshiro, 1694.
2.... Inaba, Hoki, and Mimasaka, 1711.
3.... Noto and Sado, 1729.
4.... Takata, 1751.
5.... Hirosaki, 1766.
6.... Kaga, 1799.
7.... Ogi (Sado), 1802.
8.... Kisagata, 1804.
9.... Sanjo, 1828.
10.... Sado and Uzen, 1833.
11.... Zenkoji, 1847.
12.... Hamada, 1872.
13.... Noto, 1892.
14.... Sakata, 1894.

resulting in two gigantic landslips which completely blocked the course of the above-named river for 20 days, and formed a lake 34 km in length and 1 to 4.3 km in width. The water finally broke the two enormous dams, and flooded over the regions along the Sai-*gawa* and Shinano-*gawa*, sweeping away a large number of the houses which escaped the destruction from the shock. The loss of human lives was, however, small, as due preparations had previously been taken to meet the emergency.

3. ***Sanjo (Echigo) earthquake.*** The Sanjo earthquake took place on Dec. 18, 1828, at about 8 am. The area of destructive motion was an ellipse, 50 × 17 km, along the lower course of the Shinano-*gawa*; the most central point of the meizoseismal region being between the towns of Sanjo and Imamachi, at about $\varphi = 37° 35'$ N, $\lambda = 138° 56'$ E. (See Fig. 1.) The total amount of the casualties was 1,443 killed and 1,749 wounded, while the numbers of the houses entirely and partially destroyed were 9,808 and 7,276 respectively, beside the 1,204 burnt. Among the towns severely affected were Sanjo, Imamachi, Mitsuke, Yoita, Tsubame, and Nagaoka, the first four having been almost entirely destroyed by the shock and the subsequent fires.

4. ***Uzen and Sado earthquake.*** The earthquake of Dec. 7, 1833 (4th year of Tenpo), at about 4 pm., was destructive in the island of Sado and along the coast districts of the province of Uzen. The amount of the casualties was comparatively slight, the loss of lives being about 38, in Uzen, due to the *tsunami*, or tidal waves, which followed the earthquake. The centre of the latter was submarine, its approximate postion being $\varphi = 38° 35'$ N, $\lambda = 130° 10'$ E. (See Fig. 1.)

5. ***Relation of the Zenkoji earthquake to the two others.*** The Sanjo earthquake took place 18 years 5 months earlier than the Zenkoji earthquake, the meizoseismal zones of these two shocks running in nearly the same direction, namely, N40°E–S40°W. Further, the northern prolongation of the line connecting the centres of the two disturbances passes approximately through that of the Sado-Uzen earthquake. It is extremely probable that these three large earthquakes belonged to one and the same system, namely, the seismic zone formed by the Shinano-*gawa* valley and its northern prolongation. Apparently the stress reached a maximum limit along the whole extension of this zone, so that the Sanjo earthquake occurred first at the middle, followed 5 years later by the Sado-Uzen earthquake to the NEN, and again 13 years 5 months later by the Zenkoji earthquake to the SW; the two successive distances of the centres of the three earthquakes being each equal to about 115 km.

6. ***Relation between the former destructive and the recent strong earthquakes in the Shinano-gawa valley.*** As discussed in the *Bulletin*, Vol. I, No. 3, there were five strong semi-destructive earthquakes, which occurred along the Shinano-*gawa*, respectively in the years 1886, 1887, 1890, 1897, and 1899. The line connecting their centres has been taken as defining a seismic zone, which extends from the Koshi county in Echigo in the SW direction to the vicinity of Nagano, thence turning towards the south to the vicinity of the lake of Suwa. The approximate positions of the centres of these five earthquakes are indicated by the numerals 1, 2, 3, 4, and 5, in Fig. I. From the latter, it will be observed that the zone of the recent strong shocks is in reality identical with that of the historical destructive earthquakes. Further, the recent disturbances, Nos. 1 to 5, originated along the zone in question at those points, which are outside the area of destructive motion of the Sanjo earthquake and the meizoseismal region of the Zenkoji earthquake. This fact is fully in accordance with the principle that great seismic shocks never occur at one and the same centre.

7. *Destructive earthquaks along the Japan Sea coast.* The following is the list of the larger destructive earthquakes,[*] which happened within the last 2¼ centuries, on or off the Japan Sea coast and along the Shinano-*gawa* zone :—

1. Noshiro Eqke (province of Ugo); June 19, 1694, at 7 A.M.
2. Inaba, Hoki, and Mimasaka Eqke; March 19, 1711.
3. Sado and Noto Eqke; Aug. 1, 1729. Accompanied by *tsunami.*
4. Takata Eqke (province of Echigo); May 21, 1751, at 2 A.M.
5. Hirosaki Eqke („ „ Mutsu); March 8, 1766, at 6 P.M.
6. Kaga Eqke; June 29, 1799. Accompanied by *tsunami.*
7. Ogi Eqke (Island of Sado); Dec. 9, 1802, at 2 P.M.
8. Kisagata Eqke (provinces of Uzen and Ugo); July 13, 1804, at 10 P.M.
9. Sanjo Eqke (Echigo); Dec. 18, 1828, at 8 A.M.
10. Sado and Uzen Eqke; Dec. 7, 1833, at 4 P.M. Accompanied by *tsunami.*
11. Zenkoji Eqke (Shinano and Echigo); May 8, 1847, at 9 P.M.
12. Hamada Eqke (Iwami); March 14, 1872, in the evening.
13. Noto Eqkes; Dec. 9 and 11, 1892.
14. Sakata Eqke (Uzen and Ugo); Oct. 22, 1894, at 5 P.M.

Of the above 14 earthquakes, Nos. 1, 4, 5, 8, 9, 10, 11, 12, and 14 were much larger than the remaining five. Again, the five earthquakes of Nos. 1, 5, 9, 11, and 14 originated inland, while the 7 others, namely, Nos. 3, 4, 6, 7, 10, 12, and 13, originated under the Japan Sea. The origins of the two remaining earthquakes, Nos. 2 and 8, were probably also submarine. The relative positions of the origins of the different earthquakes are diagramatically illustrated in Fig. 4, (Pl. XXXI.)

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[*] Hokkaido and Formosa excepted.

The 14 earthquakes tabulated above may be divided, so far as their time distribution is concerned, into the following 5 groups :—

Group I.

		Year	Interval
No. 1.	Noshiro Eqke.	1694	17 years
No. 2.	Inaba, Hoki, and Mimasaka Eqke.	1711	18
No. 3.	Noto and Sado Eqke.	1729	22
No. 4.	Takata Eqke.	1751	15
No. 5.	Hirosaki Eqke.	1766	

Group II.

No. 6.	Kaga Eqke.	1799	3
No. 7.	Ogi ,,	1802	2
No. 8.	Kisagata ,,	1804	

Group III.

No. 9.	Sanjo Eqke.	1828	5
No. 10.	Sado and Uzen Eqke.	1833	14
No. 11.	Zenkoji Eqke.	1847	

Group IV.

No. 12.	Hamada Eqke.	1872

Group V.

No. 13.	Noto Eqke.	1892	2
No. 14.	Sakata ,,	1894	

The five earthquakes in Group I occurred with a tolerable regularity, the average interval being 18 years. On the other hand, the three earthquakes in Group II as well as the three in

Group III occurred at short intervals ranging from 2 to 14 years; while the interval between the 1st earthquake of Group II and the last of Group I was 33 years, and that between the 1st earthquake of Group III and the last of Group II was 24 years. Again, the time interval between the earthquake of Group IV and the last one of Group III was 25 years. These facts seem to favour the supposition that the three earthquakes of Sanjo, Sado-Uzen, and Zenkoji really belonged to one and the same seismic zone both geographically and in time distribution, as explained in § 5. All the other earthquakes, with the exception of the Sakata earthquake, belonged to the Inner Seismic Zone, which runs nearly parallel to the concave side of the Japanese islands.[*] The Sakata earthquake probably belonged to another system.[‡]

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[*] See the "Bulletin of the Imp. Earthquake Inv. Com.", Vol. I, No. 2.

[‡] The Sakata, Riku-U, and Hachinohe earthquakes have been ably studied by Professors Koto, Yamasaki, and Imamura, respectively.

Note on the Relation to the Epicentral Distance of the Duration of the Preliminary Tremor of the Earthquake Motion of near Origin.

By

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Member of the Imperial Earthquake Investigation Committee.

With Pl. XXXII.

In the Jour. Sc. Coll., Tokyo Imp. Univ., Vol. XI (1899), I have given, for the relation between the duration ($=y$) of the preliminary tremor at an observing place and the epicentral distance ($=x$) of the latter, the following equation :—

$$\overset{\text{km}}{x} = 7.51 \overset{\text{sec}}{y} + \overset{\text{km}}{24.9} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This equation was, in the *Publications of the Earthquake Investigation Committee*, No. 13 (1903), slightly modified into the following form :—

$$\overset{\text{km}}{x} = 7.27 \overset{\text{sec}}{y} + \overset{\text{km}}{38} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Both of these equations, which have been deduced from the observations of the earthquakes of x less than 1,000 km and, with a few exceptions, greater than 150 km, can not be applied to the cases of very near shocks, say, of x less than 100 km. With a view of obtaining a provisionary formula for the cases of smaller x, I have examined some of the seismograms obtained at the five Formosan meteorological observatories of Taihoku, Taichu, Tainan, Taito, and Hokoto; the results being briefly stated in the following paragraph.

The earthquakes taken into consideration were the four destructive shocks in the years 1904 and 1906,* which I have specially studied and the positions of whose origins may be supposed to be fairly accurate. The observations were made with Omori horizontal pendulums of 6 to 10 times magnifications. The following table gives for each of the 4 shocks, the date and position of the origin of disturbance, and the epicentral distances and the durations of the preliminary tremor at the different stations.

FORMOSA EARTHQUAKES.

Date of Eqke.	Station.	Duration of Prel. Tremor $=y$ sec.	Actual Epicentral Distance $=x$ km.	Position of the Origin of Disturbance.
April 24, 1904.	Taihoku	28.7	221	$\varphi = 23° 20'$ N $\lambda = 120° 24'$ E
	Taichu	11.4	98	
	Taito	12.8	98	
	Hokoto	12.7	90	
November 6, 1904.	Taihoku	28.8	202	$\varphi = 23° 30'$ N $\lambda = 120° 26'$ E
	Taichu	11.2	76	
	Tainan	8.3	64	
	Taito	15.5	117	
	Hokoto	9.0	85	
March 17, 1906.	Taihoku	27.5	188	$\varphi = 23° 35'$ N $\lambda = 120° 32'$ E
	Taichu	9.0	65	
	Tainan	8.7	75	
	Hokoto	11.5	101	
April 14, 1906.	Taihoku	30.6	210	$\varphi = 23° 25'$ N $\lambda = 120° 30'$ E
	Taichu	12.0	88	
	Tainan	8.6	53	
	Hokoto	13.0	98	

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* See the "Bulletin of the Imperial Earthquake Inv. Com.," Vol. I, No. 2.

Arranging the epicentral distances, which varied between 53 and 221 km, and dividing these conveniently into 4 groups, we obtain :—

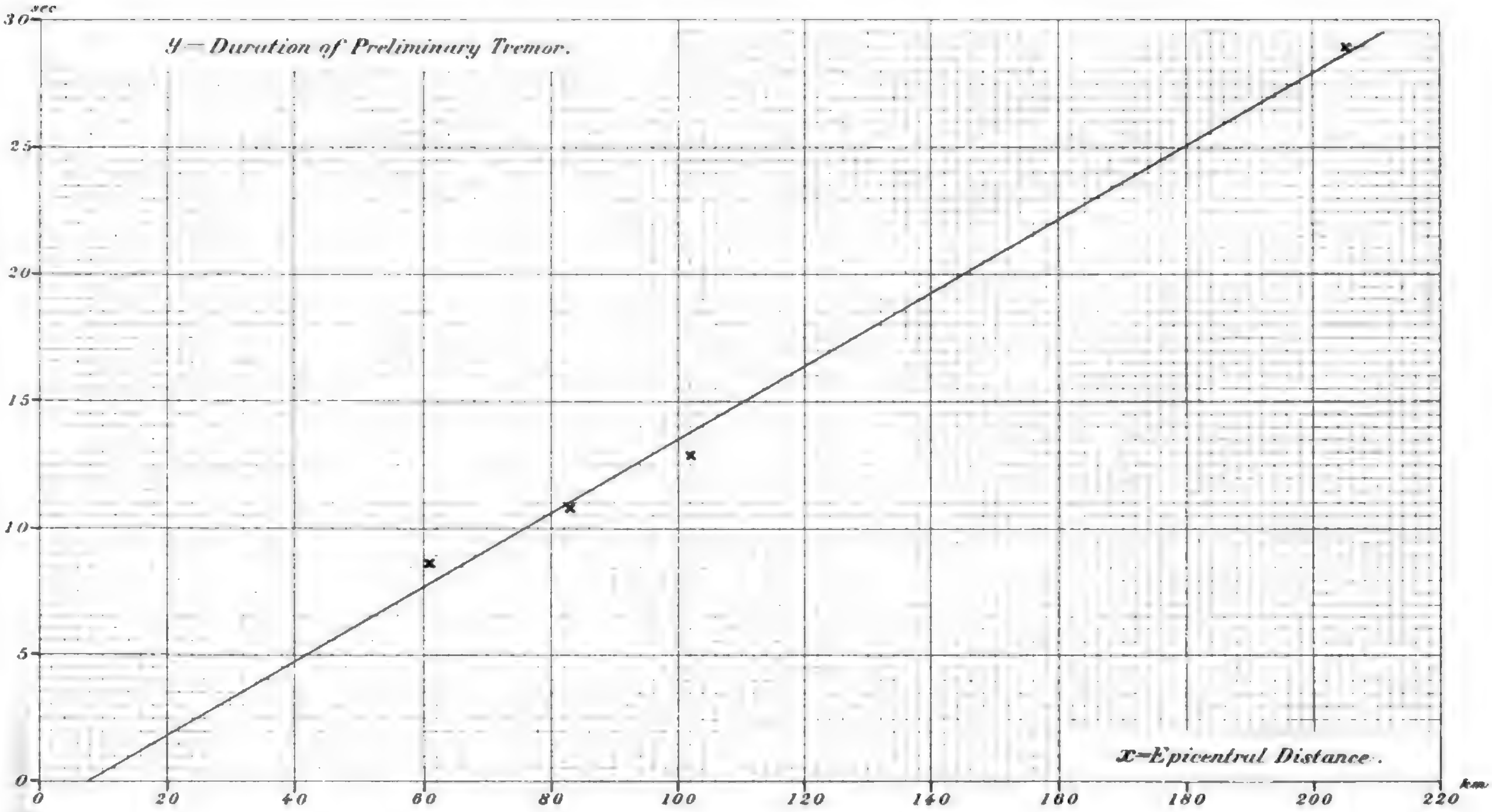
x (actual)	y	x calculated by equation (3)
221 km	28.7 sec.	
210	30.6	
202	28.8	
188	27.5	
Mean **205**	**28.9**	206
117	15.5	
101	11.5	
98	13.0	
98	11.4	
98	12.8	
Mean **102**	**12.8**	96
90	12.7	
88	12.0	
85	9.0	
76	11.2	
75	8.7	
Mean **83**	**10.7**	81
65	9.0	
64	8.3	
53	8.6	
Mean **61**	**8.6**	67

The relation between the mean values of the epicentral distance and the duration of the preliminary tremor given in the preceding table is graphically shown in the accompanying figure (Pl. XXXII). Assuming a linear equation between x and y and determining the constants from the four sets of the mean values of x and y, we obtain :—

$$x^{\text{km}} = 6.86\, y^{\text{sec.}} + 8.1^{\text{km}} \ldots\ldots\ldots\ldots (3)$$

Relation between the Epicentral Distance and the Duration of the Preliminary Tremor.

(*Near Earthquakes.*) Formosa Observations.



The figures given in the last column of the preceding table, which have been calculated by this equation, agree closely with the actual distances.

Equation (3), which may be used under the conditions

$$50 \text{ km} < x < \text{about } 200 \text{ km},$$

seems to be more convenient for the cases of near earthquakes than Equation (1) or Equation (2); the distances calculated by the two last equations being, for a small value of y, generally larger than the corresponding actual x.

Earthquake Distributions in Formosa.

By

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With Pls. XXXIII and XXXIV.

CONTENTS.

§ 1. Introduction.
§ 2. Earthquake frequency in 1904.
§ 3. Earthquake frequency in 1904-1907.

1. *Introduction.* The meteorological observatory of Taihoku was first opened on Aug. 11, 1896, and the six other observatories of Taichu, Tainan, Taito, Koshun, Hokoto and Keelung, were established in the course of the next five years, namely, between 1897 and 1901. The yearly numbers of sensible earthquakes recorded at these seven stations, which are now furnished with seismological instruments, were as follows :—

TABLE I.—YEARLY NUMBERS OF SENSIBLE EARTHQUAKES RECORDED AT THE DIFFERENT METEOROLOGICAL OBSERVATORIES IN FORMOSA.

Station. / Year.	Taihoku.	Taichu.	Tainan.	Taito.	Koshun.	Hokoto.	Keelung.
1896	—	—	—	—	—	—	—
1897	7	3	9	—	—	1	—
1898	17	5	4	—	3	2	—
1899	9	10	4	—	5	2	—
1900	5	8	4	—	1	2	—

TABLE I. *(Cont.)*

Station. / Year.	Taihoku.	Taichu.	Tainan.	Taito.	Koshun.	Hokoto.	Keelung.
1901	12	4	8	2	1	2	--
1902	13	10	12	12	5	5	6
1903	7	14	19	117*	7	6	7
1904	9	10	9	8	4	6	5
1905	12	24	8	32	3	4	5
1906	10	40*	42*	21*	11*	19*	4
1907	11	10	11	6	6	10	6
Mean.	10.2	9.3	8.8	12.0	3.9	4.0	5.5

The large yearly number for Taito in 1903 was due to the after-shocks of the strong earthquake of Sep. 7 of the same year. Similarly, the high seismic frequency in 1906 for the different stations, except Taihoku and Keelung, were due to the after-shocks of the destructive earthquakes of March 17th and April 14th in that year. These numbers, each marked in the above table by an *asterisk*, have been excluded in deducing the average values, which may be regarded as approximately giving the frequencies of the sensible seismic disturbances in the ordinary year for the seven meteorological observatories in question. It will be noticed that this frequency was about 10, namely, 8.8 to 12.0 for Taichu, Taito, Taihoku, and Tainan, but smaller and equal to about 4 for Koshun and Hokoto, and 5.5 for Keelung.

The earthquake numbers, as above described, give, however, no adequate idea of the earthquake distribution for the whole of the Island. In fact the greatest seismic activity is displayed in regions at some distances from the different meteorological observatories, namely:—(1), in the vicinity of the city of Kagi, which is situated in the south-western part of Formosa and midway between Taichu and Tainan; and, (2), at the central and northern parts of the eastern coast and at the very southern extremity of the Island. Great credit is due to Mr. H. Kondo, Director-general of the Formosa meteorological observatories, who instituted in 1907 a general system of the observation of the precipitation by establishing in different parts of the Island nearly 80 stations furnished with rain-gauges, Each of these stations sends in regularly to the Meteorological Observatory of Taihoku the monthly weather report, giving amongst others the notices of the earthquakes felt. The following table, compiled from these materials, indicates the numbers of the sensible shocks in different parts of Formosa during the four years from 1904 to 1907.

TABLE II.—YEARLY NUMBERS OF EARTHQUAKES FELT AT THE DIFFERENT METEOROLOGICAL OBSERVATORIES AND RAIN-GAUGE STATIONS IN FORMOSA. 1904—1907.

Year. / Station.		1904	1905	1906	1907	*Sum.*
天送埤	Tensohi	5	16	8	10	31
宜蘭	Giran.	19	19	23	41	79
鼻頭角	Bitokaku	2	2	2	3	7
社寮島	*Sharyoto (Keelung)	5	5	4	0	20
基隆	Keelung	1	1	2	0	5
金包里	Kinpori	0	7	4	2	9
富基角	Fukikaku	1	1	2	1	3
暖々街	Dandangai	1	1	1	0	2
火燒寮	Kashoryo	—	—	—	—	—
石底	Sekitei	8	7	8	6	21

TABLE II. *(Cont.)*

Year. Station.		1904	1905	1906	1907	*Sum.*
坪林尾	Hyorinbi	1	0	5	3	4
石碇	Sekitei	1	1	2	4	6
屈尺	Kussyaku	0	0	5	0	5
頂內埔	Chonaiho	9	4	14	7	20
臺北	*Taihoku	9	12	10	11	45
双峻頭	Soshunto	0	0	3	1	1
淡水	Tansui	2	1	2	4	7
銅鑼圈	Doraken	0	0	4	3	3
三角湧	Sankakuyo	1	1	3	3	5
白沙岬	Hakushako	9	4	5	5	18
大湖口	Taikoko	1	0	2	0	1
咸菜硼	Kansaiho	2	4	5	3	9
內灣	Naiwan	11	8	9	—	19
樹杞林	Jukirin	7	8	24	19	34
新竹	Shinchiku	2	0	1	2	4
南庄	Nansho	0	0	3	1	1
苗栗	Byoritsu	4	0	6	0	7
大湖	Taiko	1	2	14	2	5
罩蘭	Hekiran	1	6	12	2	9
後里庄	Korisho	2	0	15	1	3
臺中	*Taichu	10	24	40	10	87
水底寮	Suiteiryo	3	5	6	0	8
北港溪	Hokkokei	1	0	4	3	1
埔里社	Horisha	4	7	14	4	15
南投	Nanto	9	12	14	4	25

TABLE II. *(Cont.)*

Year. / Station.		1904	1905	1906	1907	*Sum.*
社頭	Shato	6	18	38	9	33
芦竹頭	Rochikuto	5	14	—	1	20
集々街	Shushugai	3	12	—	3	18
牛轀轆	Goonroku	8	5	13	2	15
小半天	Shohanten	3	9	20	3	15
林内	Rinnai	15	8	91	17	40
土庫	Doko	13	12	—	5	30
生毛樹	Seimoju	6	18	—	36	60
竹頭崎	Chikutok	3	19	—	65	87
嘉義	Kagi	25	33	—	19	77
達邦社	Tatsunasha	2	2	—	4	8
公田	Koden	5	8	—	10	23
鹽水港	Ensuiko	6	2	—	0	8
前大埔	Zentaiho	16	14	110	22	52
後大埔	Gotaiho	8	7	—	26	41
噍吧哖	Tabani	12	8	—	5	25
甲仙	Kosen	—	4	24	0	—
上老濃	Rono	3	0	32	2	5
南庄	Nansho (Tainan Prefecture)	15	18	69	8	41
臺南	*Tainan	9	8	42	11	71
龜洞	Kito	13	6	26	10	29
蕃薯寮	Banshoryo	14	1	5	4	19
新威	Shin-i	4	3	20	0	7
深水	Shinsui	5	1	11	2	8
阿緱	Ako	6	1	—	5	12

TABLE II. *(Cont.)*

Station.		Year. 1904	1905	1906	1907	*Sum.*
鳳山	Hozan	7	3	2	4	14
打狗	Takao	2	0	7	0	2
赤山	Sekizan	2	0	5	0	2
東港	Toko	3	0	7	1	4
內仔頭	Naishito	0	1	0	2	3
枋山	Bosan	0	0	0	1	1
恆春	*Koshun	4	3	11	6	26
鵝鑾鼻	Garanbi	30	17	12	11	58
九棚	Kyuho	2	4	2	0	6
牡丹社	Botansha	—	—	—	—	—
巴塱衛	Haroei	0	0	2	—	—
臺東	*Taito	8	32	21	6	79
成廣澳	Seiko-o	10	6	2	11	27
璞石閣	Bokusekikaku	3	19	0	1	23
拔仔庄	Basshisho	17	28	21	5	50
吳全城	Gozenjo	0	26	16	5	31
花蓮港	Karenko	10	50		22	82
澎湖島	*Hokoto	6	4	19	10	37
漁翁島	Gyooto.	2	0	17	0	2

2. ***Earthquake frequency in 1904.*** The seismic frequency during the year 1904 at the different places in Formosa is shown in Fig. 1 (Pl. XXXIII). From the latter there are seen to be four principal regions of seismic activity, as follows:—

(*a*) A nearly north-south zone, extending in the south-western part from the vicinity of Shato and Toroku to that of Banshoryo.

(*b*) Vicinity of Giran, near the northern end of the eastern coast.

(*c*) The eastern coast, between Karenko and Seiko-o.

(*d*) A limited portion about Cape Garanbi at the southern extremity of the Island.

Although Fig. 1 is a map showing the seismic frequency and therefore does not necessarily indicates the distribution of the origins of disturbances, the zone (*a*) seems on the whole to coincide with the main longitudinal earthquake zone in the south-western part of Formosa.* The northern prolongation of (*a*) passes approximately through the local centres at the vicinity of Jukirin and Taihoku and that of Hakushako at the north-western end of the Island. (*b*), (*c*), and (*d*) belong probably to a continuous zone, their higher seismic frequencies being due to the disturbances which occur along or off the eastern coast.

3. ***Earthquake frequency in 1904-1907.*** To obtain a general idea of the seismic distribution in Formosa for the interval, 1904 to 1907, I give in the last column of Table II the sum of the earthquakes recorded during the three years 1904, 1905, and 1907; the frequency for the year 1906 having been excluded on account of the great number of the after-shocks of the destructive disturbance, which took place on March 17th of that year. As is illustrated in Fig. 2 (Pl. XXXIV), the principal centres of the seismic activity, in which more than 50 shocks were felt during the 3 years in question, were as follows:—

(*A*) Kagi and the vicinity.

(*B*) The vicinity of Giran.

(*C*) „ „ Karenko.

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* See F. Omori: "Preliminary Report on the Formosa Earthquake of March 17, 1906." The *Bulletin*, Vol. I, No. 2.

(*D*) The vicinity of Basshisho.
(*E*) Cape Garanbi.

In broad features, Fig. 1 is similar to Fig. 2, and the local centres denoted by (*a*), (*b*), (*c*), and (*d*) in the preceding § are respectively identical with (*A*), (*B*), (*D*) and (*E*), here described. (*B*), (*C*), (*D*), and (*E*) may be regarded as forming a seismic zone which is situated on the eastern side of the axis, or main mountain chain, of Formosa, passing along the longitudinal valley separating the latter from the Taito coast range.* (*A*) forms the most active seat of seismic disturbances of inland origin.

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* See also the next Article.

On the Bokusekikaku and Basshisho (Formosa) Earthquake of January 11, 1908.

By

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With Pls. XXXV and XXXVI.

CONTENTS.

§ 1. Introduction.
§ 2. Time of Occurrence.
§ 3. Area of Disturbance.
§ 4. Earthquake damage.
§ 5. Approximate position of the earthquake origin.
§ 6. Relation of the earthquake of Jan. 11, 1908, to that of March 17, 1906.
§ 7. Mutual Relation of the different strong earthquakes along the eastern coast of the Island.
§ 8. After-shocks.

1. ***Introduction.**** The disastrous earthquakes in Formosa generally occurred in the densely populated south-western part of the Island, where the ground is flat.** The different places on the eastern coast are also by no means free from the visitation of strong shocks, although the amount of the seismic damage was there always insignificant. The latter circumstance is probably due to the mountainous nature of these districts and the scarcity of inhabitants, the seismic disturbances occurring, in many cases, under the ocean. The following three earthquakes were the strongest felt in the recent years along the Pacific side of Formosa.

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* The times are all given in the 1st Normal Japan Time, or that of longitude 135° E of Greenwich.

** See my paper on the Formosa earthquake of March 13, 1906. The *Bulletin*, Vol. I, No. 2.

(*a*) *Giran Eqke of June 7, 1901 ; at 9h 05m am.* The shock which was quite local, was felt strongly and caused some slight damage at the town of Giran and the vicinity :—

Giran. 5 or 6 houses had mud walls cracked, and a few roof tiles thrown down.

Shokei. One house had the roof damaged. In one case, a mud wall was thrown out of the vertical.

Hachirisha. 6 houses slightly damaged.

Suihenkyaku. 56 native houses damaged.

Taikakan. One native house destroyed.

This earthquake, which was not felt at Taito and Koshun, was *slight* at Tainan and Hokoto, *moderate* at Taihoku, and *strong* at Taichu.

(*b*) *Taito Eqke of Sept. 7, 1903 ; at 4h 14m pm.* The disturbance was felt strongly at Taito, where 92 after-shocks were recorded in the course of the following 30 days. No damage was done, the origin being sub-oceanic.

(*c*) *Karenko Eqkes of Aug. 26 and 28, 1905.* The earthquake of Aug. 26, which occurred at about 4h 52m pm., was felt slightly at Taihoku and Taichu, but insensible at Tainan, Taito, Hokoto, and Keelung. It was, however, strong at Karenko and was followed by several minor shocks. The earthquake of Aug. 28, at about 1h 23m pm., was much severer, causing at Karenko partial destruction of one ware-house and 6 native houses, besides some damage to two houses in Japanese style. This shock was also very local, the area of severe motion being limited only to the immediate vicinity of the above mentioned town. At the Gozenjo, about 10 km to the south-west of the latter, the motion was strongly felt but caused no damage. At Basshisho, about 42 km further on in the same direction, the intensity was slight. The motion was sensible and slight at Taihoku, Taichu, and Taito, but was insensible at Tainan, Hokoto, and Keelung.

The earthquake of Jan. 11 of this year, which originated near the towns of Bokusekikaku and Basshisho in the Taito prefecture, was the strongest felt in the Island since the destructive shocks of Kagi in March and April, 1906.

Earthquake of Jan. 11, 1908.

2. ***Time of occurrence.*** The observations at the different meteorological observatories in Formosa were as follows :—

Station.	Geographical Position.		Intensity of motion.	Duration of Preliminary Tremor.	Time of Occurrence.
	Latitude (N).	Longitude (E).		sec.	h m s
Taihoku.	25° 02′	121° 31′	Moderate.	18.8 (?)	0 35 14 pm.
Taichu.	24 09	120 42	Do.	—	0 32 57 (?)
Tainan.	22 59	120 12	Strong.	18.9	0 36 14
Taito.	22 45	121 09	Do.	13.9	0 36 46
Koshun.	22 01	120 44	Moderate.	25.9	0 38 30 (?)
Hokoto.	23 32	119 33	Moderate (rather weak).	23.2	0 36 08
Keelung.	25 09	121 45	Do.	—	0 36 00
Karenko.	24 00	121 33	Strong.	—	0 36 00

The observations at the 5 stations of Taichu, Tainan, Taito, Koshun, and Hokoto, were each made with an Omori horizontal pendulum of 6 times magnification; Tainan being also furnished with an ordinary Gray-Milne-Ewing type macro-seismograph. At Taihoku the pointer of the horizontal pendulum, of 10 times magnification, got out of the smoked paper soon after the commencement of the shock, and the duration of the preliminary tremor at this place estimated from the macro-seismograph record, namely, 18.8 sec., seems to be too short. Karenko had no seismological instrument, while Keelung had simply a macro-seismograph.

The times of the earthquake occurrence at the different stations are only approximate, except that at Taihoku; the probable time of occurrence at the origin itself being about 0h 35m 00s pm.

3. ***Area of disturbance.*** The earthquake was sensible all over Formosa and in Hokoto (Pescadores). The shock was also felt slightly at Ishigaki-jima (Lyukyu) at an epicentral distance of about 302 km, so that the radius of the area of sensible motion was probably a little over 300 km. As shown in Fig. 2, (Pl. XXXV), the land area of moderate and strong motion was, for Formosan shocks, unusually large and had a length and breadth of 210 and 100 km respectively; the longer axis being in the direction of NEN and SWS and coinciding with the Taito longitudinal valley. Within this area, whose western boundary was formed by the line joining the cities of Toroku and Tainan, pendulum clocks were generally stopped. According to Mr. H. Kondo, who happened to be at Karenko at the time of the earthquake, the motion there was strong and lasted 25 seconds, causing the houses to be shaken considerably, although no damage was produced. At Karenko there were some after-shocks and *jinari*.

The area of severe motion, within which seismic damage was done, included the villages of Bokusekikaku, Suibi, and Basshisho, forming probably an ellipse of length and breadth respectively of about 75 and 50 km. According to the reports from the different rain-gauge stations, the shock was preceded or accompanied by sounds, in the western half of the Island, at the four places of Suiteiryo, Nanto, Doko, and Seimoju, where the intensity of motion was moderate or slight.

4. ***Earthquake damage.*** The villages of Bokusekikaku and Basshisho are situated among the districts inhabited by the aboriginal tribes, whose dwellings are of the simplest construction with thatch roofing, and do not show signs of seismic damage; there being only a very few houses of "dokaku," or mud construction, prevalent among the native (old Chinese) population of Western Formosa. To these circumstances was partly due the small amount of the seismic damage to the buildings. There were at Bokusekikaku and Suibi three old houses totally overthrown, besides a number of the cases of partial destruction. Still there is no doubt that the intensity of motion in the epicentral area was much smaller than that on the occasion of the Kagi earthquake of March 17, 1906. At Suibi, the "byo" (native temple), the only *dokaku* building in the village constructed some 5 years ago, had its back wall entirely thrown down, while the damage to the front side facing S80°E was limited to cracks of the walls and the falling down of some roof tiles. (See Fig. 3, Pl. XXXVI). The walls of the sub-prefectural office at Bokusekikaku were much cracked, but the plasters did not fall down. The *dokaku* house of the chief official of the village of Chuka, constructed in the preceding year, was only cracked at the junctions of the walls. The newly built sub-prefectural office of Seiko-o was practically undamaged, except some slight separation of the timbers and walls.

Some landslips were caused by the shock in the vicinity of Basshisho, Suibi, Bokusekikaku, and Sangenya; part of the water of the river Shukoran-kei having been temporarily stopped by the falling of a soft rocky cliff. At a place about 2¼ km distant from Basshisho and among the valleys of the central mountain range the stream waters were from a similar cause stopped for a few days. Again, at Bokusekikaku and Chuka the ground was cracked, in some cases to a width of 1 foot.

5. ***Approximate position of the earthquake origin.*** The epicentral distances of the four meteorological observatories of Taito, Koshun, Tainan, and Hokoto, calculated by Equation (3) given on page 146 of this Number, from the durations of the preliminary tremor, are as follows :—

Station.	Epicentral Distance $= x$. Calculated by Equation (3). p. 146.
Taito	103^{km}
Koshun	186
Tainan	138
Hokoto	167

Drawing on the map of Formosa (Fig. 2), four circles about the different stations as centres and with radii respectively equal to the calculated epicentral distances given in the above table, we find that their points of intersection are near each other, enclosing a small quadrilateral in the vicinity of Basshisho. Taking also the isoseismal lines into consideration, the approximate position of the epicentre, marked in the figure by a small cross (×), seems to be at about

$$\begin{cases} \varphi = \ \ 23^\circ\ 37'\ \mathrm{N}, \\ \lambda = 121^\circ\ 15'\ \mathrm{E}. \end{cases}$$

The epicentre thus located is about 52 and 96 km distant respectively from Karenko and Taito, being nearer the former by 44 km. Now, by a curious coincidence, it happened that one Mr. Wakamatsu, in the service of the post office at Taito, happened to telephone to Karenko just before the occurrence of the earthquake in question. He received for answer the information that a strong earthquake was taking place at Karenko and was requested to wait for a moment ; some noisy sounds being simultaneously perceived through the telephone. After a short time interval, while he was wondering what was the matter, a strong shaking began to be felt also in Taito. This circumstance illustrates in a practical manner the fact of the transmission of the seismic waves. As the propagation velocity of the vibrations composing the principal portion of the earthquake motion is about 3.3 km per sec., the time difference between the occurrence of the shock at Karenko and that at Taito would have been about 13 seconds, for the distance difference above assumed.

6. ***Relation of the earthquake of Jan. 11, 1908 to that of March 17, 1906.*** The cause of the disastrous Kagi earthquake of March 17, 1906, was the formation of the Baishiko and Chinsekiryo faults, in the main direction of west-slightly-south and east-slightly-north, over a distance of 13½ km from Baishiko on the east to Dabyo on the west. It was further pointed out, firstly, that the fault was probably continued westwards to the vicinity of the town of Shinko for a further distance of about 12 km, making up a length of 25½ km; and, secondly, that this latter length corresponded only to the western half of the line of dislocation and the eastward continuation passed among the mountains for a further distance of 20 or 25 km, the total extension of the fault being some 50 km.*

From the map (Fig. 2), in which the western and the probable eastern halves of the above mentioned fault are indicated respectively by thick full and doted lines in red, the further eastward prolongation of the same line of disturbance seems to pass through the epicentre (×) of the Bokusekikaku and Basshisho earthquake of this year. My supposition is that the latter shock was a continuation of the Kagi catastrophe of 1906, the formation of the fault having been extended eastwards.

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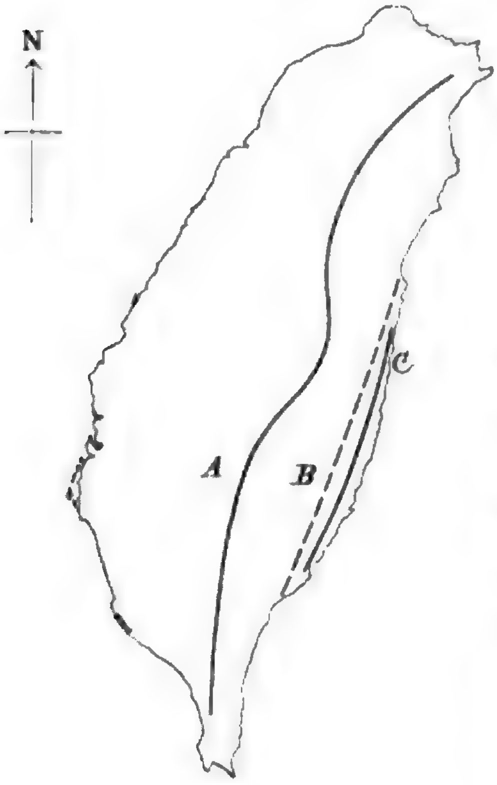
* See the *Bulletin*, Vol. I, No. 2.

If the above supposition be correct, the process of dislocation must have proceeded downwards in the eastward extension, as the focal depth of the Bokusekikaku and Basshisho earthquake was evidently great. The intensity of motion in the assumed epicentral district was not greater than in the case of the very local Karenko shock of 1905.

7. Mutual relation of the different strong earthquakes along the eastern coast of the Island. The back bone of Formosa, whose geographical feature is rather simple, is formed by the heavy mountain chain, which runs parallel to the longer axis, and is nearer to the eastern coast, of the Island. It begins in the Koshun peninsula at the southern extremity, and takes the NEN direction, till the great height of over 3,000 metres is reached among the peaks in the vicinity of Mt. Sylvia. Thence the direction of the range is turned toward ENE and reaches the sea at the neighbourhood of So-o; forming the tremendous steep cliffs along the eastern coast between the latter place and Karenko. Mt. Niitaka (Mt. Morrison) is the highest peak, not only in Formosa, but in the whole of Japan and attains the altitude of over 4,000 metres. The eastern side of the main

Fig. 1. Map of Formosa.

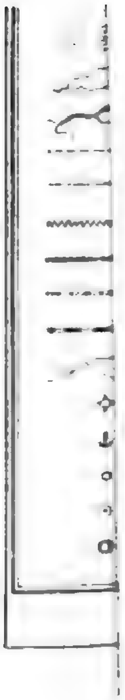
A.... General course of the Principal Mountain Range.
B.... Taito-Karenko Longitudinal Valley.
C.... Taito Coast Range.



mountain range, which is much steeper than the western side, descends abruptly into a straight longitudinal valley which extends between Karenko and Taito. To the east of this valley there is along the coast a small mountain range of about 1,000 metres height, called the Taito Coast Range. It seems probable that the Karenko-Taito longitudinal valley, whose northern and southern continuations may be supposed to run off the coast, is as explained below closely connected with the seismic phenomena in the whole eastern part of the Island. (See Fig. 1.)

Again from the maps (Pls. XXXIII and XXXIV) showing the earthquake distribution in Formosa, it seems that the more frequently disturbed regions about Giran, Karenko, Basshisho and Bokusekikaku, Taito, and Garanbi (southern extremity of the Island), belong to a continuous earthquake zone, which runs along the eastern coast of the Island, or rather along the eastern side of the main mountatin range. In the northern part, between Giran and Karenko, this zone is probably some little distance off the coast, while its middle part, between Karenko and Tainan, is probably situated inland and coincides with the Karenko-Taito longitudinal valley. The southern part of the zone, between Taito and Garanbi, is again a litle distance off the coast.

Now the Bokusekikaku-Basshisho earthquake of Jan. 11, 1908, may be taken also to belong, together with the three previous strong shocks mentioned in § 1, (*a*), (*b*) and (*c*), to the longitudinal seismic zone along the eastern coast of Formosa as above supposed. In other words, the stress was gradually increasing along the zone in question and produced strong disturbances at the different places, in the following order:—(1), Vicinity of Giran in the north; (2), off the coast of Taito in the south; (3), Vicinity of Karenko, between (1) and (2), but nearer to the former; (4),



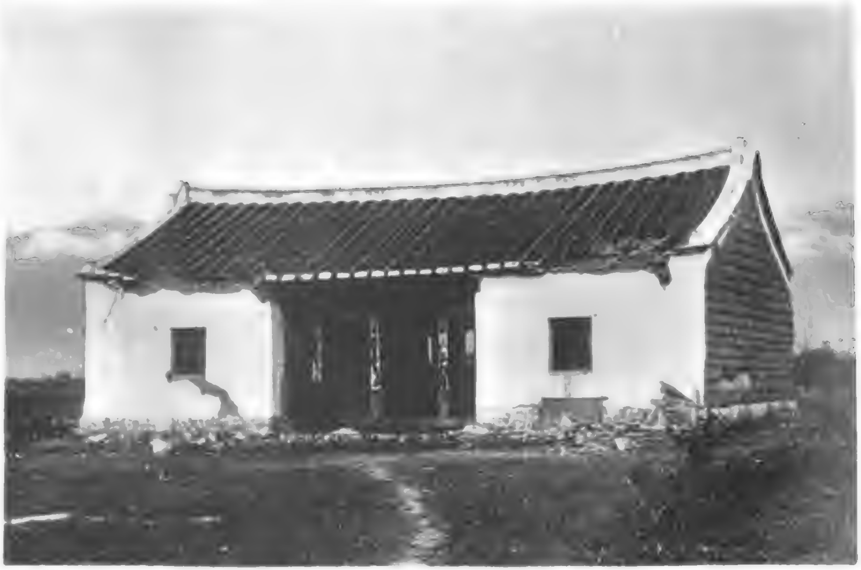


Fig. 2. The *Byo* (Temple) at Suibi, damaged by the Earthquake of Jan. 11, 1908.

vicinity of Bokusekikaku and Basshisho, between (3) and (2). (See Pls. XXXIII and XXXIV.) For other cases of the successive occurrence of strong or destructive shocks along an earthquake zone the reader is referred to the "*Bulletin*," Vol. I, Nos. 1 and 3.

8. ***After-shocks.*** At Basshisho the number of the after-shocks felt till 10 am. on the following day was 20 or 30, and there were several *jinari*, or earth sounds which seemed to proceed from some distance. At Bokusekikaku there were also a number of after-shocks. The following is a list of the shocks and sounds subsequent to the initial disturbance, observed by Mr. H. Kondo during his travel in the Taito prefecture :—

(January 1908)

11th.	Karenko.	Slight shock at 0.38 and 0.50 pm.
12th.	,,	,, ,, 0.34 pm.
13th.	Gozenjo.	,, ,, 7.30 and 8.42 pm.
14th.	In the vicinity of Gozenjo.	*Jinari* at 11.25 am.
,,	Bataian.	*Jinari* at 7.16 pm.
,,	,,	,, ,, 0.09 am.
15th.	Basshisho.	Sound and slight shock at 0.54 pm.
,,	Suibi.	Sound and slight shock at 8.02 pm.
,,	,,	Slight shock at 8.19 pm.
16th.	Sangenya.	Moderate earthquake at 6.07 pm., followed by others.
17th.	,,	Moderate shock at 2 am. After the 17th, the shocks became rarer.

In conclusion I must express my thanks to Mr. H. Kondo, who have kindly put at my disposal the materials and the results of his observations respecting the earthquake.

On the Earthquakes of the Fuji Volcanic Chain.

By

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With Pls. XXXVII–XXXIX.

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1. ***Introduction.*** As stated below, the submarine earthquakes of May 13, 1908 seem to have originated at a point between Cape Omaezaki (province of Totomi) and the Hachijo-jima. The latter is one of the islands belonging to the Fuji volcanic chain, and is at a distance of about 290 km due south of Tokyo. Let us first examine the relation between the activity of this chain and that of the "external seismic zone," which runs parallel to the Japan arc on the Pacific side.

2. ***Activity in recent years of the External Seismic Zone.*** The majority of the recent larger Japan earthquakes originated from the northern part of the "external seismic zone," namely, off the eastern coasts of the Main Island and the Hokkaido, extending in the south to the mouth of the Tokyo Bay. (See the *Bulletin*, Vol. I, No. 2.) Their frequency varied of course from year to year, as will be seen from the following table, which gives the annual numbers of the submarine earthquakes, whose land area of sensible motion was over 7,000 square *ri*,* and which originated from the region under consideration.

TABLE I.—YEARLY NUMBER OF THE EARTHQUAKES WHICH ORIGINATED OFF THE NORTH-EASTERN COAST OF JAPAN.

Land area of Sensible motion > 7,000 sq. *ri*.

Year.	Number of the Earthquakes.
1901	5
1902	12
1903	5
1904	3
1905	2
1906	2
1907	4

From the above table, it will be seen that the larger earthquakes of the submarine origin occurred 12 times in 1902, but were much rarer and had the average annual frequency of 2.8 in the years after 1904. This decrease of the seismic frequency for the zone in question is also clearly shown by Table II, which gives for the interval of 1892 to 1907 the yearly number of those earthquakes, each of which was felt strongly, moderately, or slightly, along the north-eastern coasts of Japan over a land area greater than 4,000 sq. *ri*.

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* 1 *ri* = 2.4 miles or 3.927 km.

TABLE II.—YEARLY NUMBER OF THE EARTHQUAKES, WHICH ORIGINATED OFF THE NORTH-EASTERN COASTS OF JAPAN,

And which were each felt *strongly*, *moderately*, or *slightly* over
a land area greater than 4,000 sq. *ri*.

Year.	Number of the Earthquakes.	
1892	0	
1893	1	*Mean* **3.6**
1894	5	
1895	1	
1896	3	
1897	8	
1898	1	*Mean* **3.6**
1899	2	
1900	5	
1901	4	
1902	6	
1903	0	*Mean* **1.8**
1904	2	
1905	3	
1906	2	
1907	2	

According to the above table, the larger and stronger earthquakes occurred 8 and 6 times respectively in the years 1897 and 1902; the average annual frequencies during the two successive five year intervals of 1893–1897 and of 1898–1902 being each equal to 3.6. During the last 5 years, 1903–1907, the seismic activity was much smaller, the average frequency being 1.8. Thus it will be seen that the large submarine earthquakes whose origins were near Pacific coasts of the northern Japan decidedly decreased in number since 1903. It is probable that this decrease will continue for several years to come, and that the centre of seismic activity on the outer side of Japan will be in future transferred along the "convex seismic zone" southwards to the sub-oceanic region off the coasts of Tokaido and Nankaido, between the peninsula of Izu and the Island of Kyushu. In the mean while, the activity along the Fuji volcanic zone seems to have been increasing during the recent years.

3. ***Recent activity of the Fuji volcanic zone.*** The series of the islands (see the map, Fig. 1) belonging to the Fuji volcanic chain has, within the last a few years, been unusually active in

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ERRATA.

p. 167, lines 3 and 2 from bottom, *for* "strongly, moderately, or slightly," *read* "violently, strongly, or moderately."

p. 168, Table II, *for* "strongly, moderately, or slightly," *read* "violently, strongly, or moderately."

Rock (to the south-east of the Aoga-shima), in April, probably between the 7th and 13th, 1906. The outbursts continued for about one week, a great quantity of pumice having been found floating on the sea surface.

As regards the seismic activity, there were, since 1890, fifteen larger or stronger earthquakes which originated along the Fuji zone islands; the date, time of occurrence, approximate position of the origin, and area of disturbance* for each of these shocks, numbered 1 to 16, being given in Table III. The earthquakes numbered 2′, 3′, 4′, 5′, 6′, 7′, 9′, 10′, 11′, 13′, 14′ and 15′, given for the sake of comparison, are those which do not belong to the zone in question, but which occurred within a short time interval before or after the shocks 2, 3, 4, 5, etc., respectively.

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* The area of disturbance signifies here the area within which the motion was felt or recorded by the ordinary Gray Milne-Ewing type seismographs.

TABLE III.—LIST OF THE LARGER EARTHQUAKES WHICH ORIGINATED ALONG THE FUJI VOLCANIC ZONE. 1890-1908.

Eqkes Nos. 2′, 3′, 4′, 5′, 6′, 7′, 9′, 10′, 11′, 13′, 14′, and 15′ are the larger disturbances which preceded or followed the shocks under consideration.

No.	Date.	Approximate Position of Eqke Origin.	Time of Occurrence at Origin.	Area of Disturbance. (Longer axis × shorter axis.)
1	**April 16, 1890.**	**Vicinity of Miyake and Mikura Islands.**	**$9^{h}\,30^{m}$ pm.**	**Land area of sensible motion = 4740 sq. *ri.***
2	**Feb. 12, 1896.**	**In the sea of Izu.**	**6 38 am.**	**$150^{ri.}\times 120^{ri.}$**
2′	„ 14, „	Tokyo Bay.	1 58 am.	110 × 60
	„ „ „	NW. part of Musashi.	2 04 am.	110 × 65
3	**May 7, „**	**Do.**	**2 37 pm.**	**150 × 140**
3′	„ „ „	Vicinity of Kyoto.	6 38 am.	120 × 60
4	**Jan. 18, 1897.**	**In the sea of Izu.**	**9 27 pm.**	**120 × 90**
4′	„ 17, „	Suzaka (Shinano).	5 36 am.	130 × 110
5	**March 27, 1898.**	**In the sea of Izu.**	**3 24 am.**	**170 × 110**
5′	„ „ „	Off the S. coast of Sagami.	11 25 pm.	120 × 100
6	**Jan. 31, 1900.**	**In the sea of Izu.**	**2 37 am.**	**180 × 120**
6′	Feb. 1, „	Off the E. coast of Mutsu.	4 22 am.	250 × 150
7	**Nov. 5, 1900.**	**$\varphi=33^\circ 43'$ N; $\lambda=139^\circ 06'$ E. Near the Islands of Miyake, Mikura and Kozu.**	**4 41 pm.**	**200 × 140**
7′	„ 6, „	Off the SE. coast of Awa-Kazusa Peninsula.	6 14 pm.	120 × 80
8	**„ 9, „**	**Some distance to the South of No. 7.**	**2 54 am.**	**180 × 140**

TABLE III. *(Cont.)*

No.	Date.	Approximate Position of Eqke Origin.	Time of Occurrence at Origin.	Area of Disturbance. (Longer axis × shorter axis.)
9	**Nov. 19, 1900.**	**In the sea of Izu.**	**$10^{h}\ 58^{m}$ pm.**	**$130^{ri.} \times 80^{ri.}$**
9′	,, ,, ,,	N. part of Yamato.	4 40 am.	130 × 70
10	**Feb. 20, 1902.**	**Vicinity of Hachijo-jima.**	**10 50 am.**	**190 × 150**
10′	,, 21, ,,	Off the E. coast of Mutsu.	0 35 am.	260 × 170
11	**June 3, 1903.**	**Vicinity of Hachijo-jima.**	**0 28 pm.**	**180 × 100**
11′	,, 2, ,,	Off the E. coast of Mutsu.	7 59 pm.	150 × 90
12	**Nov. 13, 1904.**	**Vicinity of Ogasawara-jima.**	**9 49 am.**	**Land area of sensible motion = 590 sq. ri.**
13	**June 7, 1905.**	**Vicinity of Oshima.**	**2 40 pm.**	**220 × 120**
13′	,, 2, ,,	In the Inland Sea.	2 40 pm.	450 × 200
	,, 4, ,,	,,	3 08 am.	90 × 50
	,, 6, ,,	,,	8 32 pm.	80 × 40
14	**May 4, 1907.**	**Vicinity of Ogasawara-jima.**	**5 37 pm.**	**600 × 400**
14′	,, 5, ,,	Off the E. coast of Hitachi.	2 16 am.	220 × 180
15	**May 13, 1908.**	**Between Hachijo-jima and Omae-zaki.**	**5 23 am.**	**400 × 250**
	,, ,, ,,	**Do.**	**5 37 am.**	**400 × 200**
15′	,, 14, ,,	Central part of Hitachi.	10 57 am.	40 × 30
	,, 15, ,,	S. part of Rikuzen.	10 10 am.	100 × 50

Of the 15 earthquakes, Nos. 1 to 15, the strongest were the three Nos. 1, 7, and 13, each of which was semi-destructive at some of the islands within the meizoseismal area, and caused some damage such as cracks of the ground, landslips of cliffs, etc. No. 1 was felt severely in the islands of Miyake and Mikura, and No. 7 in these two as well as in the island of Kozu. Eqke No. 14 originated near the island of Oshima. The positions of the origin of disturbance of the 4 shocks Nos. 7, 11, 13 and 15 are indicated in Fig. 2. Of the remaining earthquakes, Nos. 10 and 11 originated in the vicinity of the Hachijo-jima, while Nos. 12 and 14 originated in the vicinity of the Ogasawara-jima.

The following table gives some of the results of the seismographical observations at Tokyo, Osaka, and Mizusawa, relating to the earthquakes Nos. 6-14. (Eqkes No. 15 are considered later on.)

TABLE IV.—EQKES NOS. 6-14, OBSERVED AT TOKYO, OSAKA, AND MIZUSAWA.

Time of Occurrence $= t$.
Total Duration of the Preliminary Tremor $= y$.
Duration of the 1st preliminary Tremor $= y_1$.
" 2nd " " $= y_2$.

No.	Date.	Tokyo.		Osaka.		Mizusawa.
		t	y	t	y	t
6	Jan. 31, 1900	2h 37m 31s am.	33s $y_1 = 15$ $y_2 = 18$			
7	Nov. 5, "	4 41 42 pm.	27 $y_1 = 17$ $y_2 = 10$			
8	" 9, "	2 55 03 am.	99 $y_1 = 56$ $y_2 =$ [illegible]			
9	" 19, "	10 58 39 pm.	25 $y_1 = 12$ $y_2 = 13$			
10	Feb. 20, 1902	10 49 25 am.	30.1	10h 50m 10s am.	103s $y_1 = 52$s $y_2 = 51$	10h 50m 22s am.
11	June 3, 1903	0 27 48 pm.	25.1	0 28 20 pm.	63	0 28 55 pm.
12	Nov. 13, 1904	9 48 50 am.	48.5	9 47 29 am.	—	—
13	June 7, 1905	2 39 30 pm.	17.	2 40 18 pm.	50	2 40 33 pm.
14	May 4, 1907	5 38 24 pm.	96.	5 38 53 pm.	—	5 38 54 pm.

Calculating, for each of Eqkes Nos. 11 and 13, the epicentral distances (x) by the formula $x^{km} = 6.86\, y^{sec} + 8.1^{km}$,* we find :—

Eqke No. 11 ....Tokyo......180^{km}; Osaka......440^{km}
Eqke No. 13 ....Tokyo......125 ; Osaka......351

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* This Number, p. 146.

As shown in the map (Fig. 2), the origin of Eqke No. 13, determined by the intersection of the two circles drawn about Tokyo and Osaka respectively with radii proportional to the distances here obtained, is found to be quite close to the island of Oshima, which volcano ($\varphi=34^\circ$ 43′ N, $\lambda=139^\circ$ 24′ E) was probably the real centre of the disturbance. The origin of Eqke No. 11 is similarly found to be about 70 km to the south-west of the island of Hachijo. The Tokyo epicentral distance of Eqke No. 7 was, according to the calculation, 193 km and its origin was probably near to Miyake-jima, approximately at $\varphi=34^\circ$ 3′ N, $\lambda=139^\circ$ 22′ E. These three earthquakes, together with the shock of May 13th of this year, thus seem to have originated all along the chain of the Izu volcanic islands; the others having their centres in the same neighbourhood or southwards in the vicinity of Ogasawara-jima (Bonin Islands).

4. *Relation between the earthquakes of the Fuji volcanic zone and those originating off the north-eastern coasts of Japan.* According to Table III, the majority of the larger earthquakes, which belonged to the Fuji volcanic chain, and whose area of disturbance had, in each case, a longer diameter greater than 100 *ri* (=400 km), were accompanied within a day or so by similar ones originating elsewhere in Japan or off its north-eastern coasts. Before conceiving any relation between these different groups of earthquakes, however, it is necessary to examine the average frequency of larger earthquakes in the whole of Japan. This is indicated in the accompanying table, for those years in which the shocks Nos. 2, 3,........11, 13, 14 and 15 took place.

TABLE V.—YEARLY NUMBER OF LARGER EARTHQUAKES.
WHOLE JAPAN.

Year.	Number of Eqkes, whose land area of disturbance was greater than 1,000 sq. *ri*.	Number of Eqkes, whose longer axis of the area of disturbance was greater than 100 *ri* (=400 km).
1896	38	36
1897	36	34
1898	62	54
1900		72
1902		75
1903		59
1904		50
1905		84
1907		71

The annual earthquake number in Japan during the interval under consideration varied between 34 and 84, giving the average value of 59, which is equivalent to one larger shock occurring every 6.2 days. This is 7 times longer than the average interval of **21.6** hours (Table VI) between the different earthquakes of the Fuji volcanic zone and the shocks which accompanied them. Hence it is probable that the earthquakes Nos. 2′, 3′, 4′,....., which either preceded or followed the Eqkes Nos. 2, 3, 4,....., were really related to these latter.

The eleven earthquakes, 2′, 3′, 4′,.....may be divided into two groups, (i) and (ii), according as they preceded or followed those of the Fuji volcanic zone, as shown in the following table.

TABLE VI.—RELATION OF THE EARTHQUAKES OF THE FUJI VOLCANIC ZONE TO THOSE OF THE OTHER ORIGINS.

Eqke. Nos.	Origin of the Eqke by which that of the Fuji Volcanic Zone was		Time interval by which Eqke of the Fuji Volcanic Zone was			
	preceded...(i)	followed...(ii)	preceded by (i)		followed by (ii)	
			day	hour	day	hour
2′-2	....	Tokyo Bay.	....		1	19
3-3′	Vicinity of Kyoto.	....	0	8	....	
4-4′	Vicinity of Suzaka (Shinano)	....	1	16	....	
5′-5	....	Off the S. coast of Sagami.	....		0	20
6′-6	....	Off the E. coast of Mutsu.	....		1	2
7′-7	....	Off the SE. coast of the Awa-Kazusa Peninsula.	....		1	2
9-9′	N. part of Yamato.	....	0	18	....	
10′-10	....	Off the E. coast of Mutsu.	....		0	14
11′-10	....	do.	....		0	16
13-13′	Inland Sea	....	0	18	....	
14′-14	....	Off the coast of Hitachi.	....		0	9
15′-15	....	Hitachi.	....		1	5
		Mean......	0	21	0	23
			General Mean...........		22 hours.	

It will be seen from the above table that there is apparently a certain regularity in the order of occurrence of larger earthquakes along the different seismic zones. All the earthquakes of Group (ii) originated off the north-eastern coasts (including Tokyo Bay) of Japan, while those of Group (i) originated in the central part of the Main Island or in the Inland Sea. Whether these interesting relations are also fulfilled in the future remains to be seen. It is true that the number of the shocks of Group (i) is too few and only four. But the uniformity of the Pacific origin of all the 12 shocks of Group (ii) is striking. Confining our attention to the latter group alone, we may, as a provisionary conclusion, suppose that, when the seismic stress along the Japan arc reaches a maximum limit, and an earthquake first occurs along the Fuji volcanic zone, an equal or greater disturbance is likely to originate after about one day off the eastern coast of the Main Island or Hokkaido. That is to say, the Fuji zone, or the series of the islands belonging to it, forms a very sensitive seismic belt, and gives rise to the earthquake or volcanic eruption, which serves as a fore-runner to another in the northern part of the principal or external seismic zone.

5. ***Volcanic eruptions.*** Of the three volcanic eruptions mentioned in § 3, the first and the third, which occurred not very far from Izu islands group, respectively at Tori-shima and near the Bayonnaise Rock, were each accompanied by a marked seismic activity. Thus, the eruption of Tori-shima took place between the night of 7th and that of 9th, in August 1902, the larger Japan earthquakes during this epoch being as follows :—

Date. (Aug., 1902)	Approximate Time of Occurrence at Origin.	Origin of Earthquake.	Longer and Shorter axes of Area of Disturbance.
7	$0^{h}\,36^{m}$ pm.	Bay of Tokyo.	$160^{ri.} \times 70^{ri.}$
,,	6 22 pm.	Off the coast of Mutsu.	250 × 150
8	8 37 am.	Sahara (Shimosa).	200 × 120

It may be added that there was no large earthquake in any part of Japan during the 11 days preceding the 7th of August, and also during the 11 days succeeding the 8th of August.

The submarine eruption near the Bayonnaise Rock probably occurred between 7th and 13th of April, 1906, (i.e. simultaneously with the great outbursts of the Vesuvius), there having been the following six earthquakes during the 7 days from 4th to 14th (Formosa excepted):—

Date. (April, 1906)	Approximate Time of Occurrence at Origin.	Origin of Earthquake.	Longer and Shorter axes of Area of Disturbance.
4	$10^{h}\ 04^{m}$ am.	Off the coast of Rikuzen.	$130^{ri.} \times 70^{ri.}$
5	11 50 am.	,, ,, Iwaki.	240 × 180
6	7 29 pm.	Off the E. coast of Nemuro.	350 × ?
8	2 52 pm.	Off the E. coast of Awa-Kazusa Peninsula.	160 × 70
9	2 38 am.	Off the coast of Iwaki.	230 × 160
11	7 08 pm.	NW. part of Mino.	140 × 90

In this case again there was no large earthquake in Japan (Formosa excepted) during the 11 days preceding the 4th of April, and during the 9 days succeeding the 11th of April.

6. ***Note on volcanic earthquakes.*** The earthquakes originating along the Fuji volcanic chain are probably of the volcanic origin, that is to say, they are the effects due to the activity of the volcanic energy, resulting in the sudden formation or extension of a subterranean cavity and other disturbances. Earthquakes of this nature need not necessarily be small, and are sometimes quite different in magnitude from those, which accompany actual volcanic eruptions or explosions and which are of purely surface origins. As instances of strong volcanic earthquakes of moderate extension, I may mention the shocks on April 21st and 22nd, 1792, which preceded the final catastrophe.

of the Unsen-*dake* (in the province of Hizen, Kyushu),* which caused in the town of Shimabara some damage to buildings and cracks of the ground about 1 inch in width. The earthquake of April 2, 1868, in the island of Hawaii, which attended the eruption of Mauna Loa in that year, is another example. It caused some damage to buildings in the vicinity of the mountain, in addition to a landslip which produced a remarkable mud stream. The shock at Pompeii, which had caused a considerable amount of damage to the buildings in that city 16 years prior to its final destruction by the eruption of the Vesuvius, was also evidently of the same category.

The proper volcanic earthquakes are thus sometimes strong, semi-destructive, or even locally destructive, but seem as a rule not to attain the magnitude of a large destructive shock.

Earthquake of May 13, 1908.

7. ***Different shocks on May 13, 1908.*** As is usually the case with stronger earthquakes of the Fuji volcanic zone, the principal shock of May 13th, 1908, at about 5h 23m am., was accompanied by many minor ones, the earliest of which occurred at 4h 44m am. on the same day. The following table is a list of 13 of the shocks of this group, which were sensible or were recorded by the ordinary Grey-Milne-Ewing type seismographs on the Main Island, during the course of the next 24 hours; the numerals within the brackets in the first column corresponding to those of the fore-shocks (Table on page 99) and after-shocks (Table X) observed at Hachijo-jima.

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* See my "Note on the Eruptions of the Unsen-dake in the 4th year of Kansei (1792)." The *Bulletin*, Vol. I, No. 3.

TABLE VII.—LIST OF THE EARTHQUAKES ON MAY 13th AND 14th, 1908, WHICH WERE SENSIBLE, OR WERE RECORDED BY THE ORDINARY GRAY-MILNE-EWING TYPE SEISMOGRAPHS.

No.	Approximate time of Occurrence at Origin.	Time of Occurrence in Tokyo.*	*Strong.*	*Moderate.*	*Slight.*	Slight (insensible) **
	[May 13th]					
	h m	h m s				
a (1)	4 44 am.	—	—	—	—	Numazu Matsumoto.
b (2)	5 06¾ am.	5 07 06 am.	—	—	—	Hachijo-jima, Numazu, Kofu, Kumagae.
c (6)	5 23 am.	5 23 22 am	Hachijo-jima, Nagatsuro, Numazu.	Yokohama, Iida, Mera, Hamamatsu Matsumoto, Tsu, Kofu, Takayama, Kyoto.	Tokyo, Yokosuka, Hikone, Osaka, Nagoya, Gifu, Niigata.	Fukushima, Mito, Yokosuka, Fukui, Yagi, Wakayama, Tokushima, Okayama.
d	5 30 am.	—	—	Matsumoto.	Yokosuka.	Numazu.
e (7)	5 37 am.	5 37 22 am.	Hachijo-jima, Nagatsuro.	Numazu, Tsu.	Tokyo, Mera, Kofu, Nagoya.	Fukushima, Mito, Yokosuka, Gifu, Hikone, Kyoto, Osaka.
f (1′)	5 54 am.	—	—	—	Kofu.	Yokohama, Numazu.
		5 57 17 am.	—	—	Yokohama.	Yokosuka, Numazu.
g (5′)	6 34 am.	—	—	—	—	Kofu.
h (8′)	7 03¾ am.	7 04 05 am.	—	—	Kofu.	Numazu.
i (10′)	7 28 am.	—	—	—	—	Kofu.
j	8 17 am.	—	—	—	—	Kofu.
k	9 23 am.	—	—	—	—	Kofu
l	9 54 am.	—	—	—	Kofu.	Numazu.
	[May 14th]					
m	1 33 am.	—	—	—	Hachijo-jima Yokohama, Kofu.	Matsumoto, Numazu, Hikone.

---

* The times of occurrence in Tokyo have been taken from the seismograms furnished by the horizontal pendulum tromometer of 120 times magnification.

** A *slight* (*insensible*) shaking means an earthquake which is insensible, but is recorded by an ordinary Gray-Milne-Ewing type seismograph.

The shock at 5h 23m am. was felt *strongly* at Hachijo-jima and within an area of 110 sq. *ri* on the Main Island, which covered the major part of Izu and a portion of Totomi, causing stoppage of pendulum clocks, overflow of liquids, etc. The area of *moderate* motion, about 1,780 sq. *ri*, extended over the provinces of Mikawa, Totomi, Suruga, Kai, Sagami, Awa, and Kazusa ; the total land area within which the motion was sensible or was recorded by the Gray-Milne-Ewing type seismographs being 8,640 sq. *ri*. At the Hachijo-jima itself, the second shock, which followed 14 minutes later, was felt much more strongly than the first. Again, of the 13 earthquakes tabulated above, only 8 were sensible on the Main Island. The earthquake at 5h 37m am., which was, according to the seismographic records at the different stations, of a magnitude practically equal to that of the principal shock, had a much smaller land area of disturbance than the latter. This was probably due to the removal of the origin of the second earthquake further southwards. The areas of disturbance of these two earthquakes are indicated in Pl. XXXIX.

8. ***Preliminary tremor and epicentre.*** Table VII gives the times of occurrence and the durations of the preliminary tremor of the two principal earthquakes, deduced from the records furnished by the Omori horizontal pendulum seismographs at Tokyo, Osaka, Mito, Mt. Tsukuba, Nagano, and Hachijo-jima, whose multiplication ratios varied from 10 to 300 times. The determination of the moment of commencement of the second shock was rendered uncertain by the superposition of the vibrations forming the end portion of the first.

TABLE VIII.—TIME OF OCCURRENCE AND DURATION OF PRELIMINARY TREMOR OF THE TWO PRINCIPAL EARTHQUAKES, OBSERVED WITH OMORI HORIZONTAL PENDULUMS.

Station.	Time of Occurrence. (am.)	Component.	Duration of Preliminary Tremor.	Instrument.	
				Proper Period.	Multiplication.
		1st Earthquake.			
Tokyo.	5^h 23^m 22^s	NS	$32.9^{\text{sec.}}$	$28.0^{\text{sec.}}$	10
		,,	34.5	48.5	20
		EW	27.4	4.7	300
		,,	25.2(?)	26.5	120
		,,	24.8(?)	61.5	15
Osaka.	5 23 35	NS	46.7	30.0	20
		EW	44.8	25.0	20
		NS	42.9	4.0	90
		EW	—	4.0	90
Mt. Tsukuba.	5 23 41	EW	40.3	4.0	90
Mito.	5 22 48	EW	45.0	28.8	20
Nagano.	—	EW	39.7	13.0	20
Mizusawa.	5 24 20	—	—	—	—
Hachijo-jima.	5 19 09(?)	EW	15.2	4.5	150
		2nd Earthquake.			
Tokyo.	5 37 00	NS	30.5(?)	28.0	10
		,,	32.3(?)	48.5	20
Osaka.	5 37 00	NS	46.1	30.0	20
		EW	45.7	25.0	20
		NS	48.0	4.0	90
		EW	48.5	4.0	90
Mito.	—	EW	47.0	28.8	20
Nagano.	—	EW	34.0(?)	13.0	20

The duration of the preliminary tremor at Tokyo seems to be somewhat shorter in the EW component than in the NS. As a provisionary measure I have adopted the value for the latter component, which corresponded nearly to the longitudinal wave. The duration for Osaka does not much differ in the two components, which may therefore be taken together. Table IX gives the mean durations of the preliminary tremor at the different places obtained by averaging the results relating to the two earthquakes.

TABLE IX.—MEAN DURATION OF THE PRELIMINARY TREMOR AT THE DIFFERENT PLACES.

Station.	Duration of Preliminary Tremor = y (*mean value*).	Epicentral Distance = x, calculated by Eq. (3), page 146.
Tokyo	$33.7^{\text{sec.}}$	239^{km}
Osaka	46.4	326
Mt. Tsukuba	40.3	284
Mito	46.0	323
Nagano	39.7	280
Hachijo-jima.	15.2	112

The epicentral distances (x) given in the 3rd column of the above table have been calculated from the duration (y) of the preliminary tremor by the equation $x^{\text{km}}=6.86\ y^{\text{sec}}+8.1^{\text{km}}$.* Drawing on the map (Fig. 4) the circles about the 6 different places as centres, with the radii proportional to the x thus obtained, the points of the mutual intersection are found to be quite close to one anothers, except those relating to Nagano. The approximate position of the epicentre marked on the map by a small cross

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* This Number, p. 146.

(×), is at about $\varphi=$ **33° 53′ N**, $\lambda=$ **138° 55′ E**, nearly midway between the island of Hachijo and Cape Omae-zaki of Totomi. (See Fig. 3.)

9. ***Fore-shocks.*** The earthquake at 5h 23m am. was preceded by 5 minor precursory disturbances. These furnish a very interesting example of the occurrence of the "fore-shocks" of earthquakes, and have been discussed in another article. (This Number, p. 99.)

10. ***After-shocks.*** Table X gives the time of occurrence, the duration of the preliminary tremor, and the maximum range $(=2a)$ of motion in the EW direction for the 12 after-shocks, which immediately followed the two principal earthquakes, the observation having been made at the meteorological observatory of Hachijo-jima with an Omori horizontal tremor-recorder of 150 times magnification.

TABLE X.—AFTER-SHOCKS OBSERVED AT HACHIJO-JIMA.

No.	Time of Occurrence at Hachijo-jima.	Total Duration.	Duration of Preliminary Tremor.	Max. $2a$.
	h m s	m s	sec	mm
1′	5 55 02 am.	—	16.5	0.19
2′	5 57 13	5 15	16.1	0.34
3′	6 13 14	1 30	15.1	0.037
4′	6 20 46	—	—	—
5′	6 33 44	0 30	14.6	0.030
6′	6 36 55	0 50	—	0.027
7′	6 55 14	0 50	15.3	0.037
8′	7 03 55	2 00	16.3	0.090
9′	7 23 00	1 10	15.9	0.030
10′	7 28 30	0 50	16.4	0.020
11′	7 49 00	1 40	14.6	0.020
12′	8 00 40	0 30	—	0.016

Except the first two, all these shocks were very small. The duration of the preliminary tremor for the different cases varied between 14.6 and 16.5 sec., giving the average value of 15.6 sec., which corresponds to an epicentral distance of about 107 km from Hachijo-jima, probably to the NW of the latter. The successive time intervals between the 12 after-shocks were as follows :—

2^{m}11^{s}
16 01 .... (*)
7 32
12 58 .... (*)
3 11
18 19 .... (*)
8 41
19 05 .... (*)
5 30
20 30 .... (*)
11 40

It will be observed that every alternate intervals, marked by *asterisks*, varied from about 13 to about 19 minutes and were much longer than the intermediate ones.

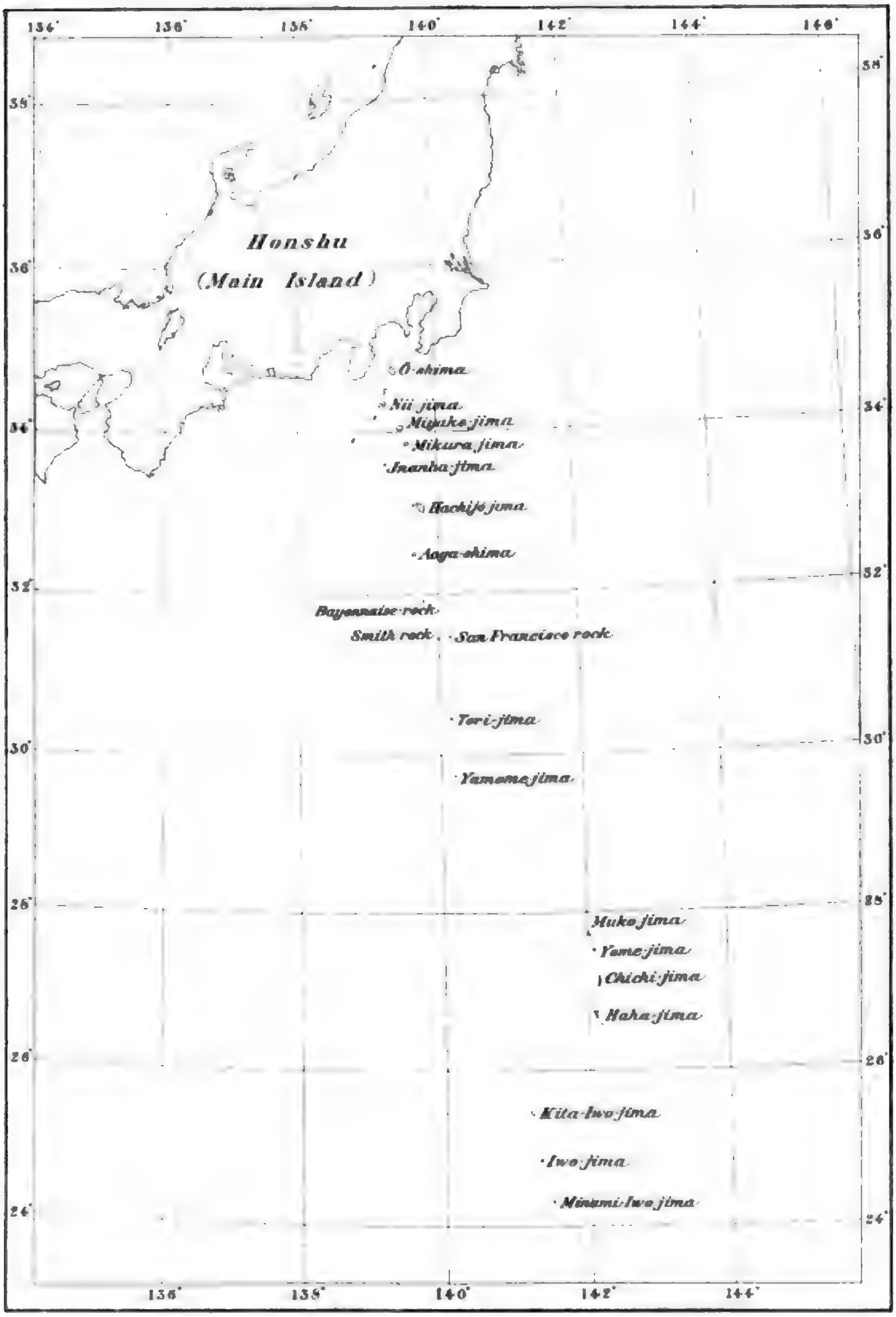
The two principle earthquakes on the 13th were followed, in accordance with the characteristic of the disturbances along the Fuji volcanic chain (§ 4), by the two following shocks which originated along the north eastern coast of the Main Island :—

May 14th : 10.57 am. .... Origin, central part of Hitachi.
„ 15th : 10.40 am. .... „ , S. part of Rikuzen.

There was no shock of the land area of disturbance greater than 1,000 sq. *ri* for the 8 days after the 2nd of the above earthquakes, and for 9 days 14 hours preceding the 1st shock on the 13th. (See Table III.)

Pl. XXXVII.

Fig. 1. Map of the Islands of the Fuji Volcanic Chain.


134°
136°
138°
140°
142°
144°
146°
38°
36°
34°
32°
30°
28°
26°
24°
Honshu
(Main Island)
Ô-shima
Nii-jima
Miyake-jima
Mikura-jima
Jnanba-jima
Hachijô-jima
Aoga-shima
Bayonnaise rock
Smith rock
San Francisco rock
Tori-jima
Yamame-jima
Muko-jima
Yome-jima
Chichi-jima
Haha-jima
Kita-Iwo-jima
Iwo-jima
Minami-Iwo-jima

Pl. XXXVIII.

Fig. 2. Map showing the Positions of the Origins of the Earthquakes which took place along the Fuji Volcanic Zone.

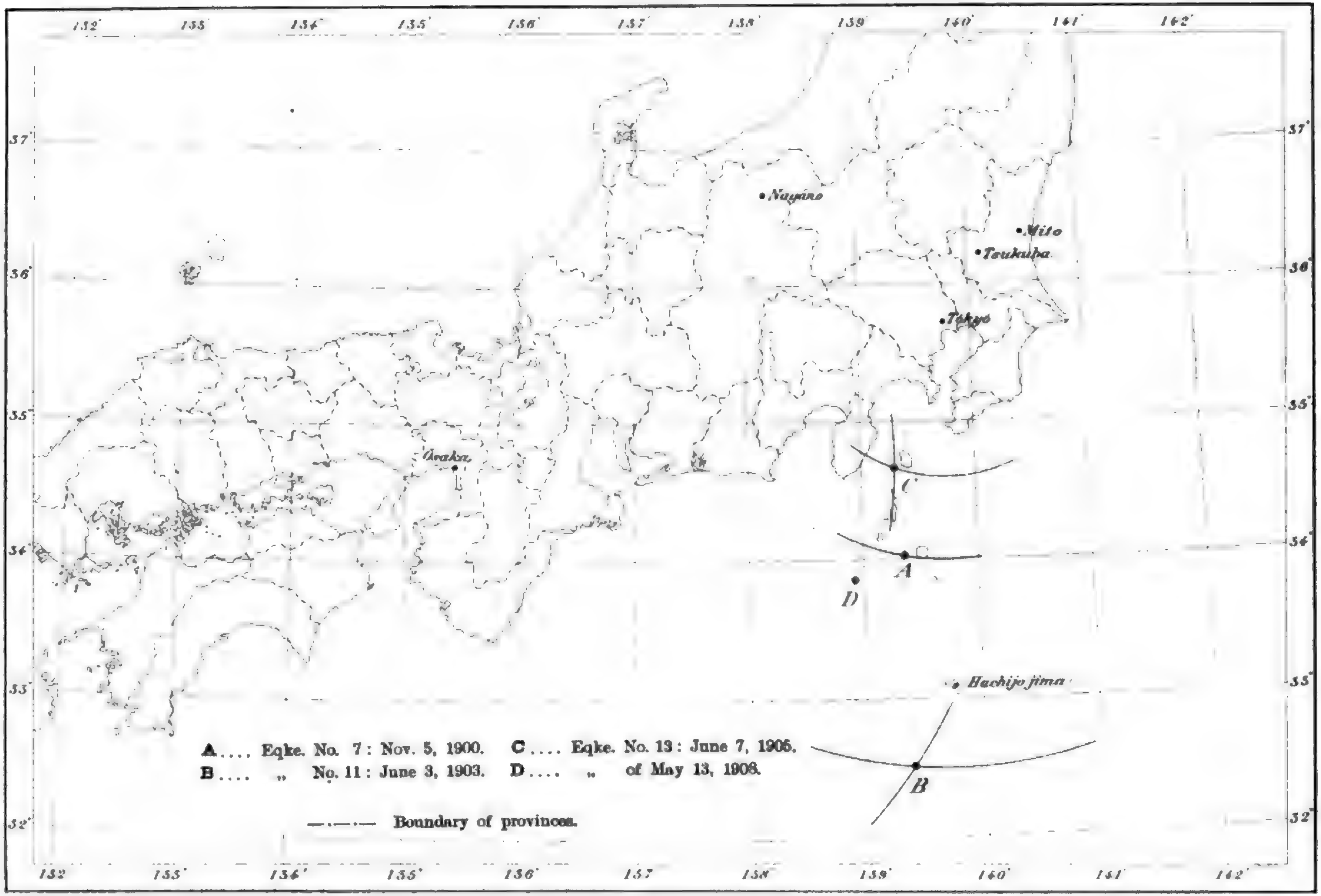
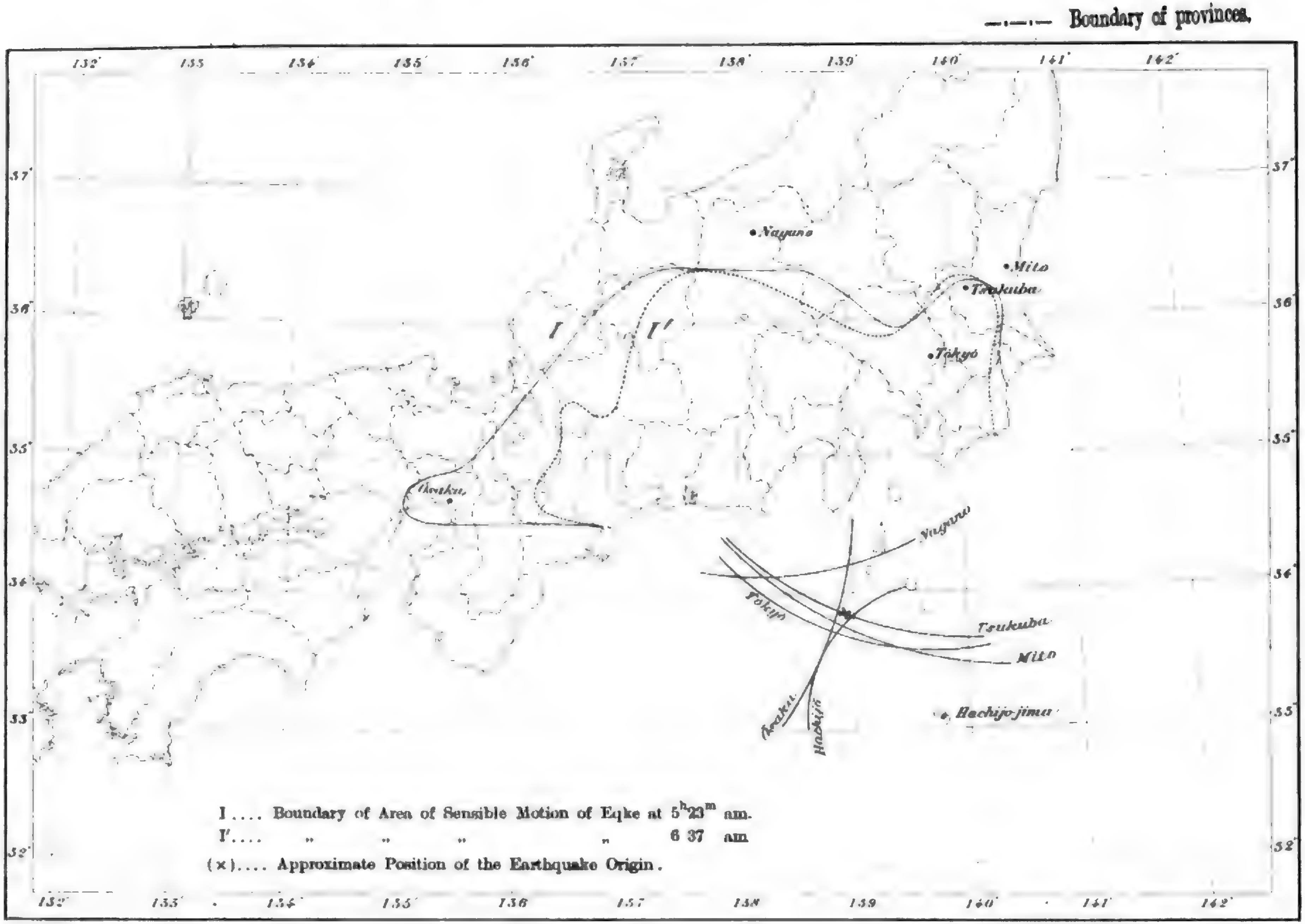

132°
133°
134°
135°
136°
137°
138°
139°
140°
141°
142°
37°
36°
35°
34°
33°
32°
Nagano
Mito
Tsukuba
Tokyo
Osaka
Hachijojima
C
A
D
B
A.... Eqke. No. 7 : Nov. 5, 1900.
B.... „ No. 11 : June 3, 1903.
C.... Eqke. No. 13 : June 7, 1905.
D.... „ of May 13, 1908.
—·—·— Boundary of provinces.

Fig. 3. Earthquakes of May 13, 1908.


—·—·— Boundary of provinces.
132°
133°
134°
135°
136°
137°
138°
139°
140°
141°
142°
37°
36°
35°
34°
33°
32°
Nagano
Mito
Tsukuba
Tokyo
Osaka
I
I′
Nagano
Tokyo
Tsukuba
Mito
Osaka
Hachijo
Hachijo-jima
I .... Boundary of Area of Sensible Motion of Eqke at 5h23m am.
I′.... " " " " 6 37 am
(×).... Approximate Position of the Earthquake Origin.

The After-shocks of the Zenkoji (1847) and the Tenpo (1830) Earthquakes.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XL and XLI.

CONTENTS.

§ 1. Introduction.
§ 2. After-shocks of Zenkoji Earthquake.
§ 3. Frequency of after-shocks of Zenkoji Earthquake compared with that of Mino-Owari Earthquake.
§ 4. After-shocks of Tenpo Earthquake of 1830.
§ 5. Comparison between the after-shock frequencies of Tenpo and Mino-Owari Earthquakes.
§ 6. Conclusion.

1. ***Introduction.*** The present note gives an account of the frequency of the after-shocks of the two great Japan earthquakes of Zenkoji and Tenpo, based on the old records given in the *Dai-Nippon Jishin Shiryo* ("Material for the Earthquake History of Japan," No. 46 of the Report [Japanese] of the Imperial Earthquake Investigation Committee, 2 Vols.)

2. ***After-shocks of the Zenkoji earthquake.**** The daily number of the after-shocks of the great Zenkoji earthquake of May 8, 1847, recorded at Matsushiro by an official in the service of the feudal lord of that place are given in Tables I and II, respectively for the first 31 days and for an interval of the 42 days between Nov. 29, 1847 and Jan. 9, 1848. There were also many *jinari*, their numbers not being included in the figures of Table I. The city of Matsushiro is about 10 km to the south of the middle point of the epifocal zone.

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* A short account of the Zenkoji earthquake has been given in p.p. 136–143, of this Number.

TABLE I.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE ZENKOJI EARTHQUAKE OF MAY 8, 1847. MAY 8—JUNE 7, 1847. MATSUSHIRO.

Date.	Number of Earthquakes.	Date.	Number of Earthquakes.
May 8	31	May 24	16
9	69	25	11
10	56	26	25
11	80	27	7
12	82	28	10
13	86	29	12
14	52	30	17
15	39	31	3
16	57	June 1	13
17	43	2	20
18	29	3	5
19	20	4	8
20	37	5	14
21	16	6	13
22	31	7	7
23	21	*Sum.*	**930**

TABLE II.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE ZENKOJI EARTHQUAKE OF MAY 8, 1847. NOV. 29, 1847—JAN. 9, 1848.

Date.	Earthquakes.			*Jinari.*	Total Number.
	Strong.	Moderate.	Small.		
1847					
Nov. 29	2	2	—	—	4
30	—	1	—	—	1
Dec. 1	—	3	—	—	3
2	—	4	5	—	9
3	—	3	3	1	7
4	—	2	2	—	4
5	—	2	—	—	2

TABLE II. *(Cont.)*

Date.	Earthquakes.			*Jinuri.*	Total Number.
	Strong.	Moderate.	Small.		
1847					
Dec. 6	—	2	—	—	2
7	—	1	—	2	3
8	2	1	3	—	6
9	—	1	1	—	2
10	—	2	—	—	2
11	—	1	—	—	1
12	—	—	1	1	2
13	—	2	—	—	2
14	1	1	1	2	5
15	—	1	—	—	1
16	—	2	—	—	2
17	—	1	1	3	5
18	—	1	—	—	1
19	—	2	—	1	3
20	—	—	—	—	—
21	—	—	—	—	—
22	2	6	1	2	11
23	—	1	3	—	4
24	—	1	—	—	1
25	—	1	—	—	1
26	—	1	—	—	1
27	—	4	—	—	4
28	—	—	—	—	—
29	—	—	—	—	—
30	—	1	—	—	1
31	—	2	5	2	9
1848					
Jan. 1	—	2	1	—	3
2	—	—	—	—	—
3	—	1	1	—	2
4	—	1	—	2	3
5	1	4	5	(Frequent)	10
6	—	1	3	—	4
7	—	1	1	—	2
8	3	5	2	—	10
9	1	—	—	—	1
Sum.	**12**	**67**	**39**	**16**	**134**

TABLE III.—MONTHLY NUMBERS OF THE SENSIBLE EARTHQUAKES RECORDED AT THE METEOROLOGICAL OBSERVATORY OF NAGANO. 1889—1907.

Month. / Year.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Sum.*
1889	0	1	1	0	1	0	0	0	0	1	0	0	4
1890	2	0	0	1	0	1	0	0	0	0	0	0	4
1891	0	0	0	0	1	0	1	0	0	2	1	2	7
1892	1	1	0	0	0	0	0	0	0	0	1	3	6
1893	0	1	1	0	0	0	0	0	0	0	2	0	4
1894	0	0	0	0	0	0	0	0	0	1	0	0	1
1895	2	0	0	1	0	0	0	0	0	0	0	0	3
1896	2	2	1	1	0	1	2	2	1	0	0	0	12
1897	4	2	0	5	5	2	1	1	0	0	2	1	23
1898	0	0	4	0	1	1	1	1	0	10	2	1	21
1899	1	0	4	3	1	0	1	0	0	0	2	0	12
1900	1	0	3	1	1	0	1	1	0	0	0	0	8
1901	1	0	0	0	0	1	2	2	1	0	2	3	12
1902	2	0	0	0	1	1	0	0	0	0	0	0	4
1903	1	1	1	0	0	0	2	2	0	0	0	0	7
1904	0	0	2	0	1	1	0	0	0	1	1	3	9
1905	1	1	1	1	1	2	6	2	0	3	1	0	19
1906	1	2	2	4	2	2	3	1	2	1	0	2	22
1907	0	1	1	5	4	4	2	2	0	2	1	2	24

The numbers of the after-shocks of the Zenkoji earthquake for the first 6 intervals of 5-days each commencing with May 9, the day after the great catastrophe, were, according to Table I, as follows:—

x	5-day Interval. (1847)	Observed Number of After-shocks $=y$	Calculated Number of After-shocks.
0	May 9—May 13	373	438
1	„ 14— „ 18	220	177
2	„ 19— „ 23	125	111
3	„ 24— „ 28	69	81
4	„ 29—June 2	65	63
5	June 3— „ 7	47	52

Denoting the 5-day interval and its corresponding after-shock frequency respectively by x and y, and calculating the constants of my equation for the frequency of after-shocks, we obtain from the foregoing table the following formula :—

$$y=\frac{296.4}{x+0.675} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

The values of y calculated by this equation for the different x's, given in the last column of the above table, may be regarded on the whole to be approximately equal to the actual after-shock frequencies.

Calculating by means of Equation (1) the seismic frequency for $x=\frac{365}{5}=73$, we find :—$y=4.0$. Hence, $6y=24$ gives the probable number of the after-shocks during the one month exactly one year after the initial great earthquake, namely, during the 30 days between April 27 and May 26, 1848. The actual number of the shock during this interval was 27.

Again, calculating as a trial the seismic frequency for $x=50$ years, we find :—

$$y=0.081\ ;\quad \frac{365}{5}\times y=5.9.$$

Thus, according to Equation (1), the annual frequency (of the after-shocks only) at Matsushiro 50 years after the Zenkoji earthquake, should be approximately 6; indicating a possibility of the continuance of after-shocks of a violent and great catastrophe for over half a century. For the sake of reference, I give in Table III the yearly numbers of the sensible earthquakes recorded at the meteorological observatory of Nagano (Zenkoji) during the 19 years between 1889 and 1907. The mean of the two last named years is 1898, which is 51 years after the date of the earthquake in question, and the average annual seismic frequency during the 19 years was 10.6, which is equivalent to the sum of the yearly number of the ordinary earthquakes and that of the after-shocks, if any.

3. ***Frequency of after-shocks of the Zenkoji earthquake compared with that of the Mino-Owari earthquake.*** The after-shocks of the Zenkoji earthquake were more numerous than those of the Ansei earthquake of Dec. 24, 1854, recorded in Tosa, and of the Nemuro-Kushiro (Hokkaido) earthquake of March 22, 1894, recorded at Nemuro.

The following table gives the daily number of the after-shocks of the Mino-Owari earthquake for the 30 days between Nov. 3 and Dec. 2, 1891, recorded *instrumentally* at the meteorological observatory of Gifu. (The after-shocks of the Mino-Owari earthquake have been discussed in detail in the Jour. Sc. Coll., Tokyo Imp. Univ., Vol. VII, and the Publications of the Earthquake Inv. Comm., No. 7.)

Pl. XL.

Frequency of the After-shocks.

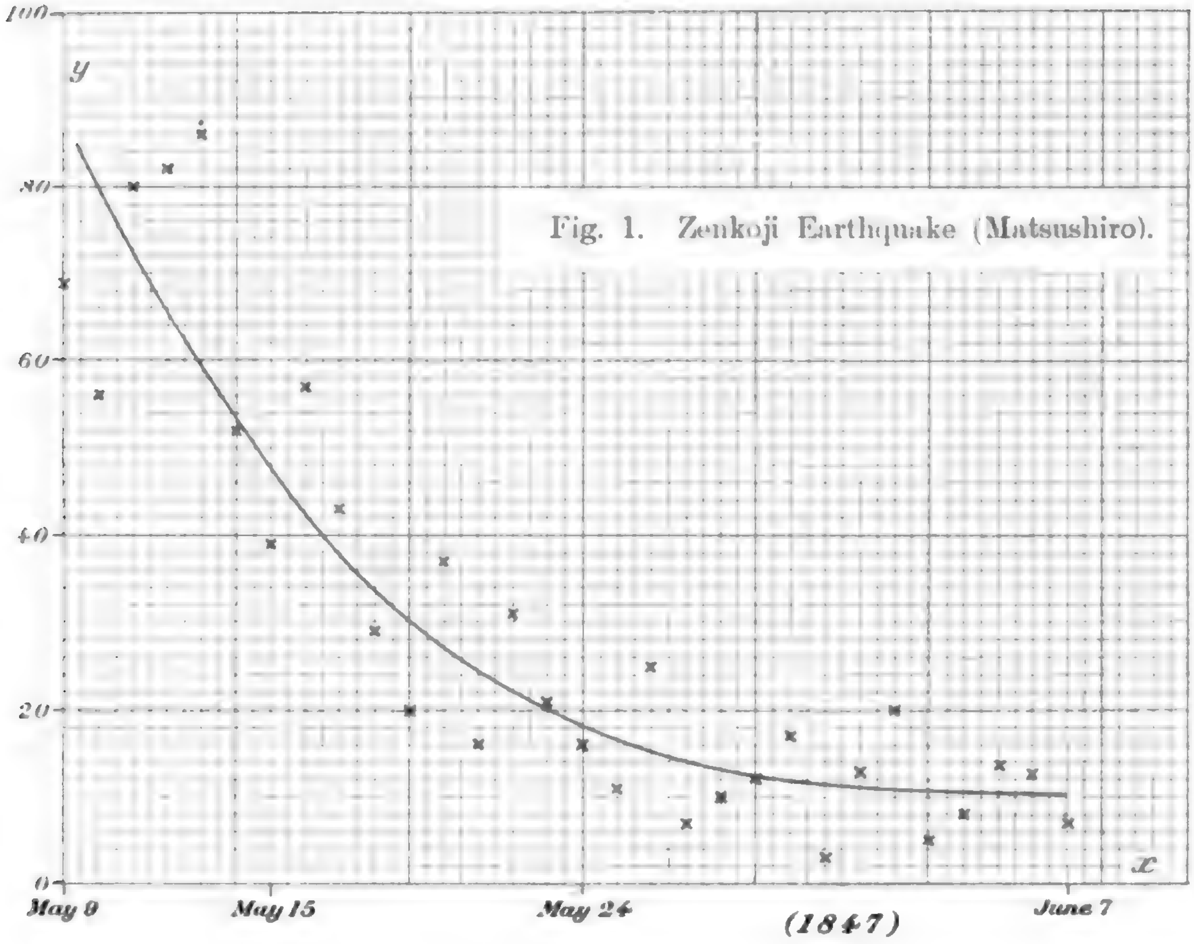

Fig. 1. Zenkoji Earthquake (Matsushiro).

x = Time, in Day.
y = Daily Number of After-shocks.

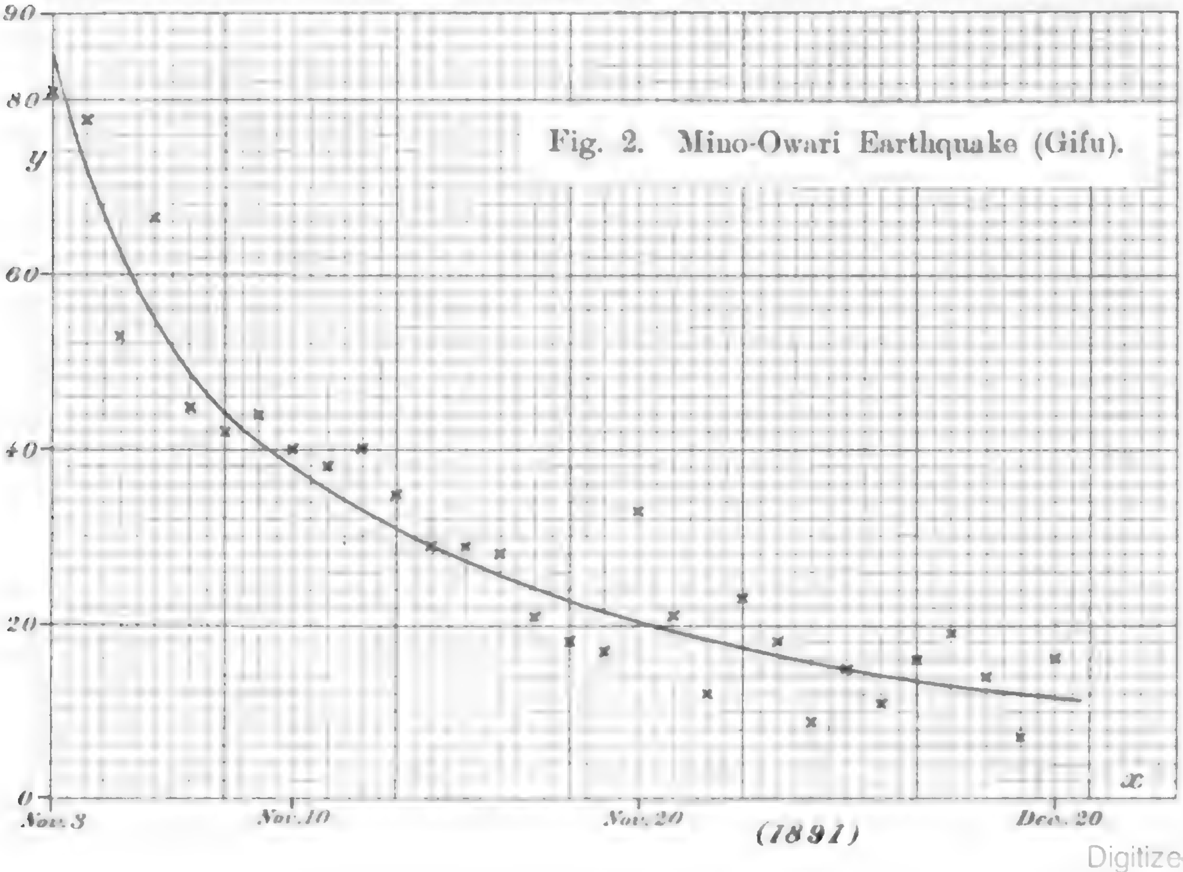

Fig. 2. Mino-Owari Earthquake (Gifu).

Frequency of the After-shocks of the Tenpo (1830) and Zenkoji (1847) Earthquakes.

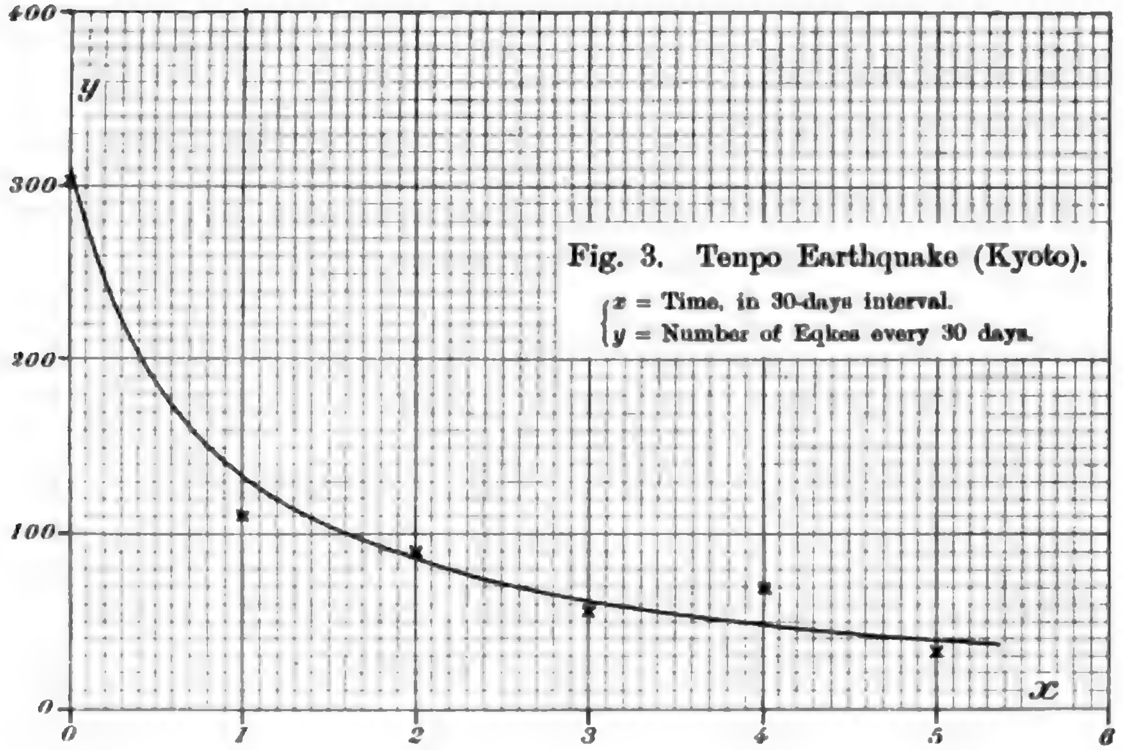

Fig. 3. Tenpo Earthquake (Kyoto).

x = Time, in 30-days interval.
y = Number of Eqkes every 30 days.

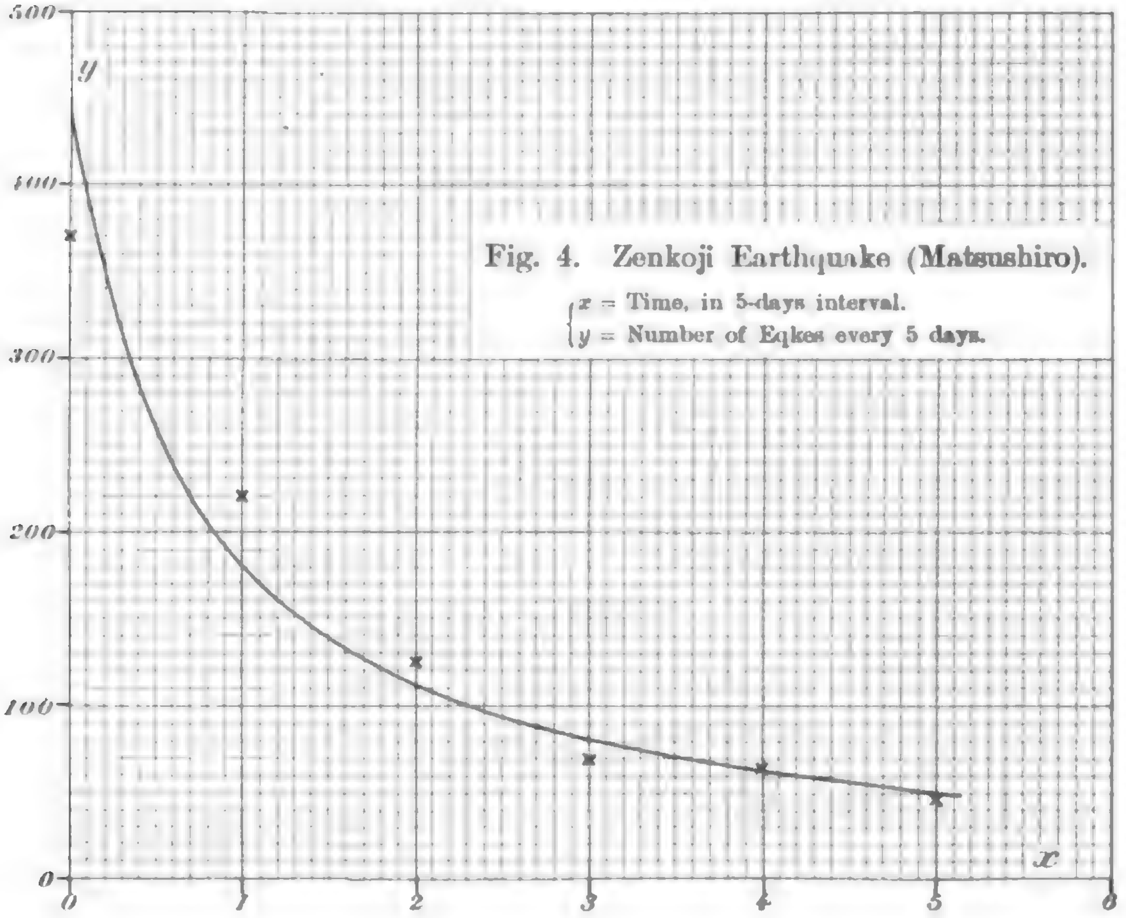

Fig. 4. Zenkoji Earthquake (Matsushiro).

x = Time, in 5-days interval.
y = Number of Eqkes every 5 days.

TABLE IV.—AFTER-SHOCKS OF THE MINO-OWARI EARTHQUAKE OF OCT. 28, 1891. OBSERVED AT THE METEOROLOGICAL OBSERVATORY OF GIFU. NOV. 3—DEC. 2, 1891.

Date.	Daily Number of Eqkes.	Date.	Daily Number of Eqkes.
Nov. 3	81	Nov. 19	17
4	78	20	33
5	53	21	21
6	67	22	12
7	45	23	23
8	42	24	18
9	44	25	9
10	40	26	15
11	38	27	11
12	40	28	16
13	35	29	19
14	29	30	14
15	29	Dec. 1	7
16	28	2	16
17	21		
18	18	Sum............	**919**

The variation with time of the after-shock frequency at Gifu during the 30 days, beginning with the 6th day after the initial disturbance, is graphically shown in Fig. 2. It will be observed that the mean curve resembles in general that in Fig. 1, which indicates the similar relation for Matsushiro with respect to the Zenkoji earthquake, during the 30 days beginning with the 2nd day after the latter. Further the total numbers of the after-shocks of these two great earthquakes during the respective 30 days intervals were nearly alike, namely, 919 and about 900.

The following is a comparison of the after-shock frequencies of the two earthquakes under cosideration during the 30 days, respectively (i) 7 months and (ii) 1 year after their occurrence :—

Zenkoji Eqke.		Mino-Owari Eqke.	
30 days Interval.	Number of After-shocks.	30 days Interval.	Number of After-shocks.
(i) Dec. 1-30, 1847.	73 shocks. 12 sounds.	(i) May 28-June 26, 1892.	23 shocks. 11 sounds.
(ii) April 27-May 26, 1848.	27 shocks. numerous sounds.	(ii) Oct. 28-Nov. 27, 1892.	46 shocks. 8 sounds.

Hereby it is to be noticed that the record of the Mino-Owari after-shocks, which was made instrumentally at the meteorological observatory of Gifu, includes a number of insensible shakings and may be taken to be much more accurate than that of the old Zenkoji shocks, which was carried on without instrumental aid.

From what has been said above it seems that the number of after-shocks of the Zenkoji earthquake of 1847 was not less than that of the Mino-Owari earthquake of 1891.

4. ***After-shocks of the Tenpo earthquake of 1830.*** The earthquake of the 1st year of Tenpo (1830), on Aug. 19, which caused considerable damage in the city of Kyoto and the vicinity, was followed by numerous after-shocks whose daily numbers at Kyoto are given in Table V; their total number in the interval of 6 months up to Feb. 28, 1831, being 681. The numbers of the after-shocks during the successive intervals of 30 days, denoted by $x=0, 1, 2, 3, 4,$ and 5 respectively, were as follows :—

x	30 days Interval.	Number of the after-shocks actually recorded at Kyoto $=y$.	Number of the after-shocks calculated by Equation (2).
0	Aug. 20, 1830-Sept. 18, 1830.	302	306
1	Sept. 19, „ -Oct. 18, „	111	134
2	Oct. 19, „ -Nov. 17, „	90	86
3	Nov. 18, „ -Dec. 17, „	57	63
4	Dec. 18, „ -Jan. 16, 1831.	71	50
5	Jan. 17, 1831-Feb. 15, „	33	41

The relation between the time x and the corresponding seismic frequency y, illustrated graphically in Fig. 3, is found to be as follows:—

$$y=\frac{237.9}{x+0.777}\ldots\ldots\ldots\ldots\ldots(2)$$

The figures in the last column of the preceding table have been calculated by Equation (2). As a trial, putting $x=60\times12=720$ (or approximately 60 years), we find $y=0.33$. Hence, $12y=4$ is the approximate calculated value of the annual seismic frequency in Kyoto, about 60 years after the earthquake in question, provided its after-shocks be supposed to have been continued for so long a time interval. Now, the value of x considered above corresponds to the year 1890, and the average annual number of earthquakes recorded at the Kyoto meteorological observatory during the 11 years between 1885 and 1895, was, as shown in the following list, approximately 5, agreeing fairly well with the result deduced from Equation (2).

YEARLY NUMBER OF EARTHQUAKES IN KYOTO. 1885–1895.

Year.	Number of Earthquakes.	Year.	Number of Earthquakes.
1885	5	1891	102*
1886	2	1892	25*
1887	6	1893	5
1888	5	1894	6
1889	2	1895	14
1890	2	*Mean.*	**5**

* The numbers for 1891 and 1892 have been omitted in taking the mean, as the majority of the disturbances in these two years were the after-shocks of the Mino-Owari earthquake of Oct. 28, 1891.

TABLE V.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE KYOTO EARTHQUAKE OF AUG. 19, 1830. KYOTO. AUG. 20, 1830—FEB. 28, 1831.

Year.	1830					1831	
Day. / Month.	VIII	IX	X	XI	XII	I	II
1		13	4	2	3	3	2
2		11	4	6	3	0	2
3		12	2	4	3	4	2
4		11	1	1	1	4	1
5		4	1	4	2	4	2
6		2	3	2	1	2	0
7		5	3	2	1	1	1
8		6	4	1	3	2	1
9		6	9	2	3	2	3
10		5	3	6	1	3	1
11		5	3	0	2	4	2
12		6	4	7	2	2	1
13		6	4	4	2	1	0
14		12	3	5	1	2	3
15		7	4	5	1	3	3
16		3	4	1	1	4	2
17		3	1	2	2	1	3
18		3	3	3	2	0	2
19	(Great Eqke.)	3	3	2	4	0	3
20	20	1	2	0	2	0	2
21	20	11	1	1	2	0	2
22	20	4	3	1	3	0	3
23	20	1	4	2	3	1	0
24	12	2	2	2	2	0	0
25	13	3	3	3	1	0	0
26	13	9	5	3	2	1	0
27	13	6	3	2	2	0	0
28	13	6	5	2	0	0	0
29	13	1	3	2	3	2	—
30	13	4	1	2	2	2	—
31	12	—	1	—	2	2	—

5. ***Comparison between the after-shock frequencies of the Tenpo and Mino-Owari earthquakes.*** The following table gives the number of after-shocks during the successive 30 days intervals for the Tenpo and Mino-Owari earthquakes, beginning respectively with the 2nd and the 42nd days after the initial disturbances.

Tenpo Eqke of 1830 (Kyoto).		Mino-Owari Eqke of 1891 (Gifu).	
30 days Interval.	Number of After-shocks.	30 days Interval.	Number of After-shocks.
(Commencing with the 2nd day after the Earthquake)		(Commencing with the 42nd day after the Earthquake)	
$x=0$	302	Dec. 8, 1891–Jan. 6, 1892	294
1	111	Jan. 7, 1892–Feb. 5, „	110
2	90	Feb. 6, „ –March 6, „	72
3	57	March 7, „ –April 5, „	62
4	71	April 6, „ –May 5, „	73
5	33	May 6, „ –June 4, „	37

The numbers of the Mino-Owari after-shocks, which are the numbers of the earthquakes instrumentally observed at Gifu and do not include the cases of the *jinari*, or mere sounds, will thus be seen to be very nearly equal, on the whole, to the corresponding figures for the Tenpo earthquake. That is to say, the monthly after-shock frequency during the earlier epoch of the latter earthquake was practically identical with that of the former, with a time retardation of 40 days. (See Figs. 3 and 4.)

6. ***Conclusion.*** The foregoing §§ seem to indicate that the after-shocks of great earthquakes are governed by time relations which are more or less alike in the different cases. The three disturbances of Zenkoji, Tenpo, and Mino-Owari, all originated along great earthquake zones, the similarity of the causes probably tending also to the similarity of the phenomena of after-shocks.

Note on the Seismic Stability of the Piers of the Naisha-gawa Railway Bridge, Formosa.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XLII & XLIII.

In connection with the seismic experiments on the fracturing and overturning of columns, described in the "Publications of the Earthquake Investigation Committee," No. 4, I have used for the fracturing the formula

$$a = \frac{Igf}{x_0 fW},$$

in which the different symbols have the following significations:

a = Acceleration of the earthquake motion necessary for fracturing a given column, supposed to be uniform in section or else to have a vertical axis or plane of symmetry.

g = Acceleration due to the gravity = 9,800 mm/sec^2.

F = Tensile strength of the column at the section of fracture.

x_0 = Half width of the section of fracture in direction parallel to the earthquake motion.

f = Height of the centre of gravity of the portion above the section of fracture.

W = Weight of the fractured portion of the column.

In the practical application of the above formula to the calculation of the strength of bridge piers, chimneys, walls, etc., there is always a great uncertainty respecting the value of the tensile strength F; it being impossible that each of such masonry structures should have a perfect homogeneity of strength of material. A column is therefore broken by the earthquake shock at the weakest place near the theoretical section of fracture. Again, a brick structure of large dimensions requires a certain length of time for the hardening of the mortar joints, such that the latter would be a good deal compressed before their conversion into perfectly solid elastic bodies. From this latter circumstance it seems that, at the mortar joints, where the brick work is almost invariably broken, tension will tend to set in immediately with the bending of the column. From these considerations, I have in my former papers simply taken the tensile strength of the brick work into consideration. For certain masonry structures, however, we may more logically take the quantity F in the above equation as denoting the tensile strength of the material increased by the weight per unit area of the section of fracture of the mass above the latter; it being absolutely necessary for the practical applications of the results that the strength of the material should not be over-estimated. Let us now consider, as an example, the seismic stability of the tall piers of the Naisha-*gawa* bridge in Formosa.

The single track Naisha-*gawa* bridge on the Formosa main railway line, consists of nine 60′ plate girders supported by two abutments and eight piers of masonry (Fig. 3), with embedded iron frame. As the ground is of a soft rocky formation, there is no well sinking, the heights of the piers, including the thickness of the foundation, being as follows :—

Northern, or Taihoku-end, Abutment.	27′	0″
No. 1 Pier	70	7
No. 2 „	92	6½
No. 3 „	114	5

No. 4 Pier	114′	5″
No. 5 „	114	3
No. 6 „	110	3
No. 7 „	105	0.5
No. 8 „	105	0.5
Southern, or Taichu-end, Abutment	46	9

Thus the six piers Nos. 3 to 8 are each taller than 105′, the construction in masonry of these high piers having been necessitated by the peculiar conditions of climate in Formosa, which cause iron spikes, bolts, etc. to rust quickly, and which render the maintenance in proper manner of high trestle works of iron extremely difficult.

Weakest section. In considering the seismic stability of the high piers of the Naisha-*gawa* bridge, we must first determine the approximate position of the weakest section, or the height where these structures are likely to be broken in case of a violent earthquake. If each of these piers be regarded as a "tall column," it would behave as a high brick chimney and be broken by the earthquake shock at about two-thirds of its height. If the column be, on the other hand, regarded as a "short column," then it would be weakest at, or near, the base. Thus it is first necessary to determine the length of the vibration period, which is proper to each of the columns and on which depends the classification of the latter with respect to the height of the section of fracture. The period, whose exact value can only be found from an actual measurement, may be estimated, so far as the order of magnitude is concerned, from a comparison with other bridge piers whose vibrations have been investigated. Thus for instance, the tallest of the piers of the single track Kizu-*gawa* bridge of Kwansai Railway, has a height of 60′ and supports the ends of a 200′

Pratt truss and a 100′ Warren girder. This pier stands directly on native rocks, and therefore its motion may be regarded as that due to its whole height; the periods of the transverse and longitudinal vibrations being respectively between 0.30 and 0.15 sec., and between 0.31 and 0.14 sec.* As now the bed of the Formosa river in question is rocky in nature, and not muddy, the piers of the Naisha-*gawa* bridge are to be regarded as vibrating approximately with their bases as centres; the period being, when inferred from the case of the Kizu-*gawa* bridge, probably 0.5 sec. or so., that is to say, much shorter than the period of the large destructive earthquake motion. From these considerations we may conclude that each of the high piers of the Naisha-*gawa* bridge would behave on the occasion of a destructive earthquake, not as a tall brick chimney, but is to be regarded as a "short column," and is weakest at the base.

Stability of the piers. Let us consider the stability against the earthquake motion of the two tallest piers, Nos. 3 and 4, of the Naisha-*gawa* bridge. As shown in Fig. 4, each of these two piers, rectangular in section, is 114′ 5″ in height, and is 10′ × 6′ at the top, and 22′ 11″ × 20′ 0″ at the base or the ground level; there being at the foot on the up-stream side a buttress 19′ 3½″ in height. The foundation, constructed to suit the nature of the ground, is 14′ 5″ in thickness. Further, the metal frame embedded in each of the piers consists of 8 iron rods, 1½″ in diameter, reaching from a few feet below the top down to the middle of the foundation, joined by horizontal iron bars forming a rectangle at every 10′ distance of the vertical.

Now a body of the dimensions like those of the pier under consideration can never be overturned as a whole, even when the structure simply rests on, and not fixed to, the ground.[*] Hence, the question of the seismic stability of the pier reduces itself to that of the fracture, which is, when the earthquake is sufficiently violent, most likely to take place at or near the base, as before explained.

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* See the "Publications of the Earthquake Investigation Committee," No. 12.

(i) Let us first calculate the strength of the pier at its base, or the section *B*, supposing the direction of the shock to be parallel to the length of the bridge. (See Figs. 1 and 4.)

Fig. 1.

(Section *B*)

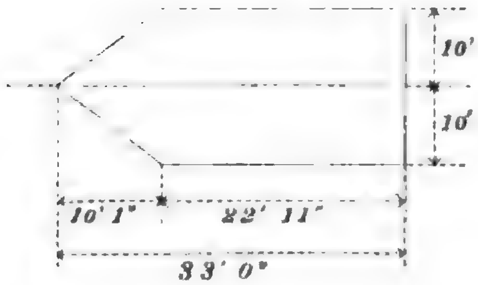
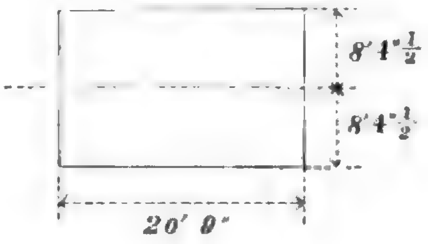


Fig. 2.

(Section *A*)



The values of the different factors in the fracture-formula for the section *B* are as follows[**]:—

I = Moment of the area of fracture about its middle axis
=351,360,000 (unit in inches).

W = { Weight of Pier above Foundation (=1524.8 tons)
+ Weight of Girder and Track system (=21.1 tons)
= Total Sum = 1545.9 tons = 3,463,000 lbs.

f = Height of Centre of Gravity of the whole structure above
Foundation = 38′ 9″ = 465″.

x = 120″.

For the tensile strength of the brick work, let us adopt a value of 50 lbs per sq. in., which is a little smaller than that obtained from the test pieces of the masonry of the Kiso-*gawa* railway bridge destroyed by the great Mino-Owari earthquake of 1891.* The strength of the iron rods, supposed to be uniformly distributed over the section under consideration, is equivalent to the reinforcing the masonry by 10.5 lbs per sq. in. of the area, assuming the ultimate strength of the iron rods to be 60,000 lbs per sq. in. Again, supposing the total weight of the pier and the girder and track system ($=W$) to be uniformly distributed over the base plane B, we obtain a pressure of 43.0 lbs. per sq. in. of the sectional area. Taking together the strength of the masonry, that of the iron rods, and the compressional effect, the effective tensile strength of the column will be

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[*] The "Publications," No. 12.

[**] The evaluation of the quantities I, W, and f for the two sections A and B have been made by Mr. Inagaki of the Railway Department of the Formosa Government General.

$$F = 50 + 10.5 + 43.0 \text{ lbs} = 103.5 \text{ lbs.}$$

The seismic stability of the pier then becomes

$$a_1 = \frac{9800 \times 351{,}360{,}000 \times 103.5}{120 \times 456 \times 3{,}463{,}000} = 1844 \text{ mm/sec}^2.$$

(ii) Let us next take the section A, whose height corresponds to the top of the buttress. (Figs. 2 and 4.) We have :—

$I = 168{,}502{,}500$ (unit in inches)

$$W = \left\{ \begin{array}{l} \text{Weight of Pier above Section } A \ (=902.1 \text{ tons}) \\ +\text{Weight of Girder and Track system } (=21.1 \text{ tons}) \\ =\text{Total Sum} = 923.2 \text{ tons} = 2{,}068{,}000 \text{ lbs.} \end{array} \right.$$

$f =$ Height of Centre of Gravity of the structure above Section A $= 29' \ 10'' = 358''$.

$x_0 = \frac{1}{2} \times 16' \ 9'' = 100''\frac{1}{2}$.

The effect on the strength of the brick work of the iron rods is equivalent in this case to an increase of 16.9 lbs per sq. in. of the sectional area ; while the pressure of the mass above the plane of fracture is 41.3 lbs per sq. in. of it. The effective tensile strength is $F=50+16.9+41.3=108.2$ lbs per sq. in. Hence the seismic stability of the pier at the section *A* is

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* The "Publications." No. 4.

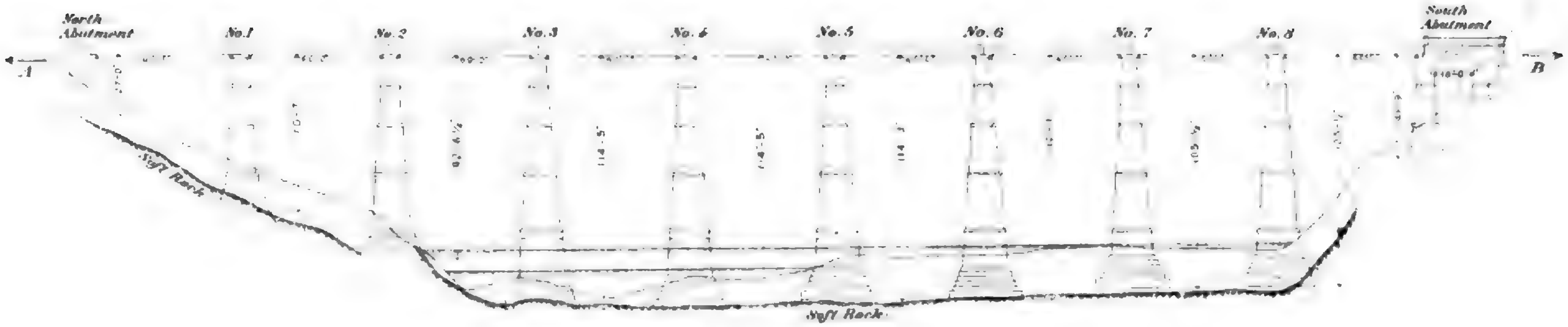
$$a_2=\frac{9800\times 168{,}502{,}500\times 108.2}{2{,}068{,}000\times 358\times 100.5}=2404\ \text{mm/sec}^2.$$

Thus a_2 is greater than a_1 in the ratio of about 4 : 3, and the pier, which is strengthened by a buttress, is still weakest at the base, its seismic stability being $a_1=1844$ mm/sec^2. As this is nearly equal to the intensity of motion in the destructive earthquakes likely to disturb the western part of Formosa, the pier in question may be considered, when the work is properly executed, to be fairly good from the seismological point of view.

Fig. 1. The Naisha-*gawa* Bridge, Formosa Railway.

Scale 1:1,000

A....Taihoku End. *B*....Taichu End.


North Abutment
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6
No. 7
No. 8
South Abutment
A
B
Soft Rock
Soft Rock

Piers Nos. 3 and 4. The Naisha-*gawa* Bridge, Formosa Railway.

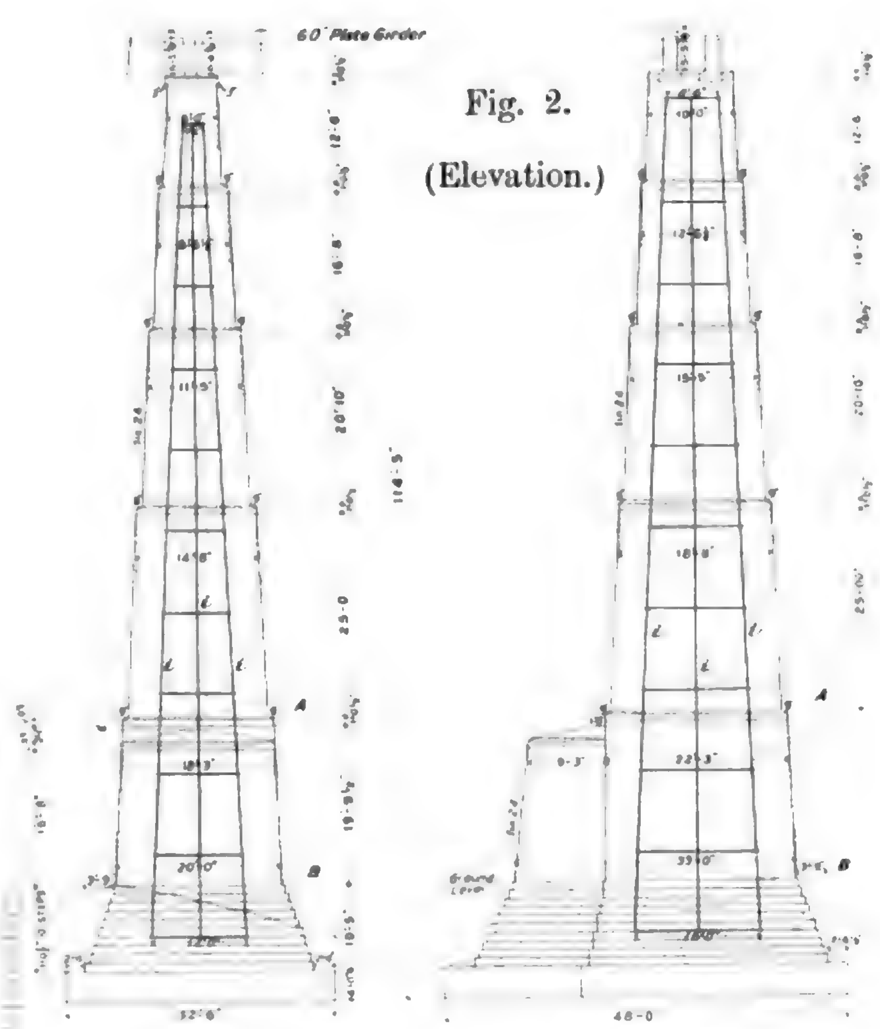

60' Plate Girder
A
B
t
Ground Level
114'-5"
12'-0"
16'-0"
20'-10"
25'-0"
32'-0"
48'-0"

Fig. 2.

(Elevation.)

Thick lines, t, are iron rods.

Scale 1 : 220.

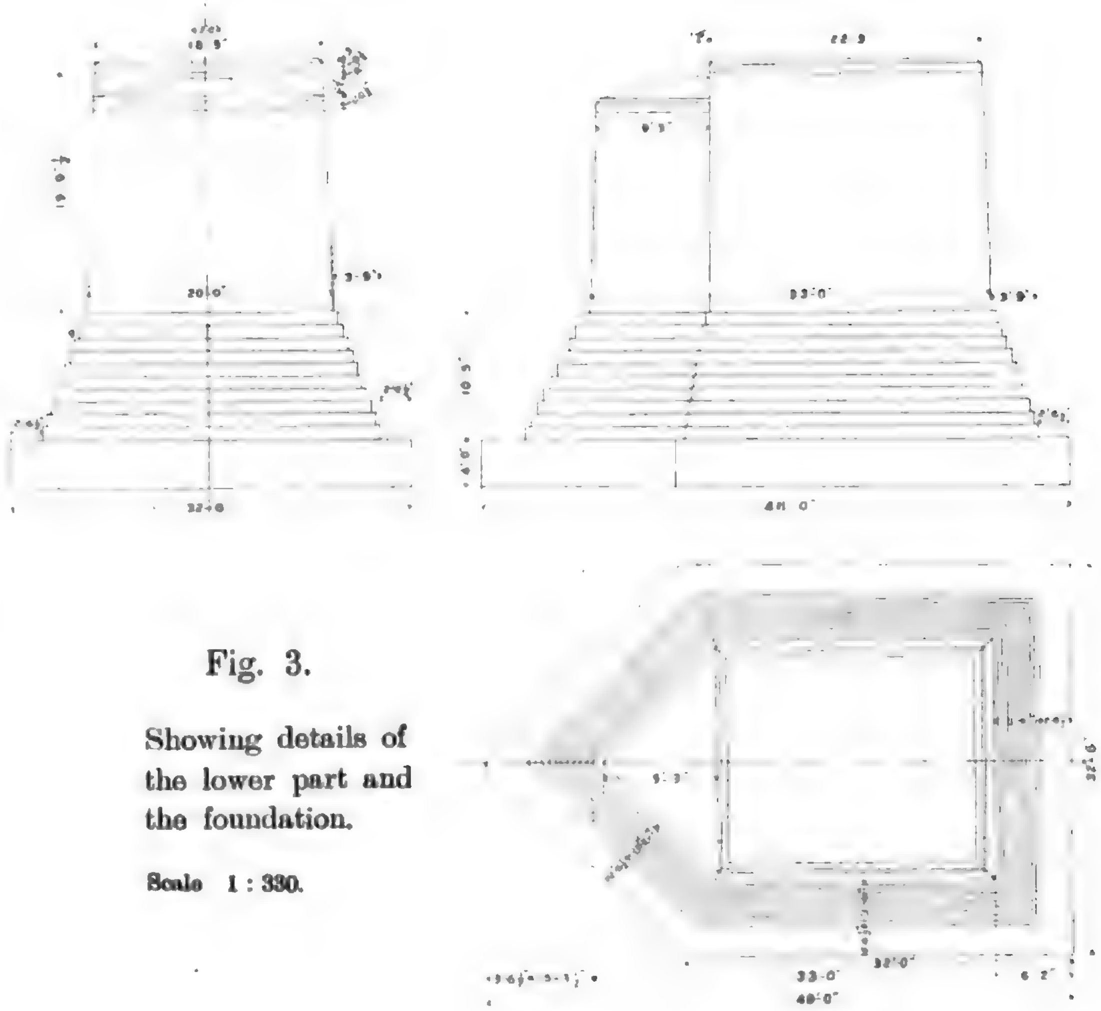

20'-0"
22'-9"
33'-0"
32'-0"
48'-0"
10'-5"
4'-0"

Fig. 3.

Showing details of the lower part and the foundation.

Scale 1 : 330.

Example of a Simple Brick Structure damaged by Earthquake.

By

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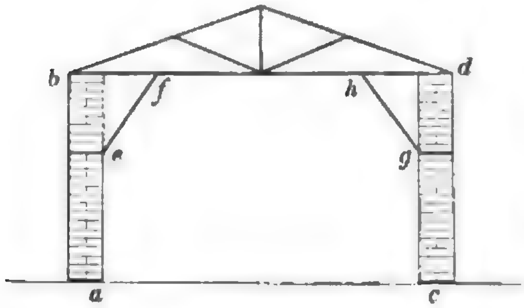
Member of the Imperial Earthquake Investigation Committee.

As an example of a very simple brick building, whose seismic stability can roughly be calculated, I consider here the market-house at the town of Ensuiko, in the Prefecture of the same name, which was damaged on the occasion of the Kagi earthquake of Nov. 6, 1904. This structure consisted merely of a roof with wooden truss supported by 20 brick posts (*ab*, *cd* in the accompanying figure.) The building covered an area of 100 *tsubo*, and was 20 *ken* in length and 5 *ken* in width, the longer axis being parallel to the N–S direction.[*] The roof had a total area of 3,960 square *shaku*, and was covered by the tiles of the native style. As the weight per square *shaku* of the roof, truss, and the tiling, is about 15 lbs, the total weight of the roof system was about 60,000 lbs, distributed with the average amount of 3,000 lbs among the masonry posts, of which there were 10 on each side with a mutual distance of 2 *ken*. The posts consisted each of 38 layers of bricks, the height being 8.6 *shaku* (=103″), and the section



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[*] 1 *ken* = 6 *shaku* = 1.82 metres. 1 *tsubo* = 1 *ken* square.

$1\frac{1}{2}$ bricks square, or 1.17 *shaku* (=14″) square. Assuming the weight per 1 cubic inch of the brick work to be 0.0603 lb, the weight of each of the columns will be 1,206 lbs. Thus the total pressure at the foot of each column was 4,206 lbs, giving an average amount of 21,5 lbs per square inch of the base area. This amount of compression, added to the tensile strength of the mortar joint of the brick work which is assumed to be about 20 lbs per sq. in., gives a value of 41.5 lbs per sq. in. for the effective tensile strength at base section of the columns. Again, the centre of gravity of the whole building is estimated to be at a height of 7.4 *shaku* (=2,230 mm), that is to say, only 1.2 *shaku* (=$36\frac{1}{2}$ cm) below the top of the supporting columns. This fact illustrates the importance of reducing the weight of the roof of a structure, in order to lessen the intensity of effects on the latter of the earthquake motion.

The seismic stability of the Ensuiko market-house, whose construction has been sketched above, is indicated by the acceleration (=a) of the earthquake motion, which is capable of fracturing the supporting columns at their weakest position, namely, the base. This can be calculated by the formula

$$a = \frac{4}{3}\frac{g x_0^3 F}{f\ W};$$

the value of the different constants being as follows:—

$x_0 = 177.5$ mm
$f = 2{,}230$ mm
$F = 41.5$ lbs per sq. in.
W = Weight supported at the foot of the column = 4,206 lbs.

The value of the acceleration a is found to be only 497 mm/sec^2. Such an intensity of motion is by no means that of what may be called a "great destructive shock," but is not much different from the maximum acceleration at Hongo on the occasion of the semi-destructive Tokyo earthquake of June 20, 1894. Thus the seismic stability of the market-house under consideration will be seen to be very low. In order to make a structure in Formosa practically earthquake proof, we must raise its seismic stability to an acceleration of about 2,000 mm/sec^2.

As is to be easily imagined, all the posts of the market-house were fractured by the earthquake of Kagi of 1904 at their bases, each being also broken at or near the foot of the timber diagonal support (*cf* and *gh* in the figure.) It is hereby to be remarked that great care must be taken in the use of trusses and ties. The existence of even an apparently insignificant discontinuity, in the form and dimension, the rigidity, or the material, invariably produces a fracture or mutual destruction at the joints.

On the Duration of the Strongest Part of Motion in Destructive Earthquakes.

By

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The disturbance due to a large earthquake is, when observed by means of a sensitive seismograph, generally found to last several hours. The duration of the sensible part of the motion is of course much shorter. Still it may sometimes happen that at or near the epicentral district of a destructive earthquake, the ground is kept for a considerable time interval in a state of shaking, owing to an incessant occurrence of the after-shocks Thus at the Kushiro-*zaki* light-house, on the occasion of the Hokkaido earthquake of March 22, 1894, at 7h 56m pm., the lamp could not be kept lighted for the 30 minutes after the great shock on account of the almost continual succession of the tremblings; the origin of disturbance being under the Pacific at a distance of about 100 km from the coast of Kushiro and Nemuro. For the sake of reference I give next the duration of the "principal portion" of the ordinary, or non-destructive, earthquake motion, obtained from the macro-seismograph observations at Miyako (province of Rikuchu), and Kyoto.

Miyako........	Duration of Principal Portion,	0.7 sec. to	26 sec.
Kyoto	"	6.0 " "	20 ".

The duration of the principal portion, which according to the observations at Miyako and Kyoto varied between 0.7 and 26 sec., may be taken in ordinary cases to be from a few seconds to about half a minute. The monvements are, however, not uniformly large throughout the principal portion of an earthquake. On the contrary, there are usually, in the seismic motion due to a near origin, a few prominent vibrations at the commencement of the principal portion which are much larger than the others. This particular feature of motion is specially well marked in strong and large earthquakes.

The following list gives the duration of the strongest part of the principal portion for the 19 destructive, semi-destructive, and severe earthquakes in Japan, measured with the Gray-Milne-Ewing type macro-seismographs at the different stations :—

No.	Date.	Earthquake.	Place of Observation.	Duration of the Strongest Part.
1	Oct. 15, 1884	Tokyo Eqke. (severe)	Tokyo	7.0^{sec}
2	June 20, 1894	Tokyo Eqke. (semi-destructive)	,,	4.3
3	Oct. 7, ,,	Tokyo Eqke. (severe)	,,	4.6
4	Jan. 18, 1895	,, ,,	,,	8.0
5	Sept. 7, 1892	Mino-Owari Eqke. (semi-destructive)	Gifu	9.5
6	Jan. 10, 1894	,, ,,	,,	6.0
7	Sept. 7, 1893	Kagoshima (Chiran) Eqke. (semi-destructive)	Kagoshima	6.0
8	Aug. 12, 1898	Fukuoka (Itoshima) Eqke. (semi-destructive)	Fukuoka	8.5
9	Aug. 31, 1896 (at $4^{h}\,20^{m}$ p.m.)	Rikuchu-Ugo Eqke. (severe)	Miyako	4.0
10	June 7, 1903	Taito Eqke. (severe)	Taito	6.9
11	April 24, 1904	Kagi ,, (destructive)	Tainan	8.6
12	Nov. 6, ,,	,, ,, (,,)	,,	13.0
13	March 17, 1906	Great Kagi Eqke.	,,	11.9
14	April 14, 1906	Kagi Eqke. (destructive)	,,	13.9
15	Jan. 11, 1906	Bashishyo and Bokusekikaku Eqke. (destructive)	,,	19.6

No.	Date.	Earthquake.	Place of Observation.	Duration of the Strongest Part.
16	April 23, 1898	Origin off the NE coast of Main Island. (severe)	Miyako	19.0 sec.
17	March 7, 1899	Origin off the E. coast of Kii. (destructive)	Wakayama	19.0
18	Aug. 31, 1896	Great Riku-U Eqke.	Miyako	26.0
19	Oct. 28, 1891	Great Mino-Owari Eqke.	Tokyo	28.0

Of the above 19 earthquakes, the twelve severe, semi-destructive, and destructive shocks, namely, Nos. 1, 2,....11, and 15, were not what may be called a great earthquake, namely, extensive and very destructive seismic disturbance. Again, the three Formosa earthquakes, Nos. 12, 13, and 14, were very destructive, having caused the following amount of damage :—

Eqke	No. 12 :	45	lives lost,	490	houses entirely destroyed.
„	No. 13 :	1249	„ „ ,	5669	„ „ „ .
„	No. 14 :	15	„ „ ,	1540	„ „ „ .

These Formosa earthquakes were, however, each quite limited in area, indicating the relative smallness of their magnitudes. Now, in the cases of the 14 earthquakes, Nos. 1 to 14, the duration of the strongest part of motion lasted 4.0 to 13.9 sec., with the average value of 8.0 seconds; being in the majority of cases less than 10 seconds. Eqke No. 15 indicated the duration of 19.6 sec.

In the two earthquakes, Nos. 16 and 17, which were large submarine disturbances, the duration were each 19 sec. Finally, the Riku-U (No. 18) and Mino-Owari (No. 19) disturbances were very great destructive shocks, the duration of the strongest motion being 26 and 28 sec. respectively.

Summary. In destructive shocks, the duration of the strongest part of motion is generally 4 to 10 seconds. When, however, the earthquake is very great, that is to say, extensive and violent, the duration in question may be nearly 30 seconds. These results will be of use in the consideration of the destructive effects of earthquake shocks on different structures.

NOTES.

Aleutian earthquake of Aug. 17, 1906. The north Pacific earthquake of Aug. 17, 1906, occurred at about 0h 11m 44s (G.M.T.), or 28m 21s earlier than the great Valparaiso shock on the same date, the approximate position of its origin being, according to my estimation, on the southern, or convex, side of the arc of the Aleutian Islands, at $\varphi=50°$N, $\lambda=175°$E.* Had the centre of this earthquake been in the same longitude but much more southwards, say at latitude 30° N or so, the shock might possibly have been felt, or registered on the cable instruments at the Midway Island ($\varphi=28° 30'$ N, $\lambda=177°$ W). Such was, however, not the case, as will be seen from the following letters, which have very kindly been communicated to me by Dr. Otto Klotz, Director of the Astronomical Observatory of Ottawa, Canada. (F. Omori.)

" J. D. Gaines, Esq., 12th April, 1907.
Supt. Cable Station,
Honolulu, Hawaii.

My dear Mr. Gaines,

"I hope that in the following I am not asking too much of you, anyway, my excuse is that it is in the interest of Science—and that means Mankind.

"You know last August 16 about 8 P.M. at Valparaiso occurred a destructive earthquake.—The earthquake instruments showed however another quake about half an hour earlier, whose origin is placed in Lat. 30° N. Long. 107° E., say about 800 west of your station Midway.—Now what I desire to ascertain is whether at Midway the cable instruments were in any way affected either mechanically, that is, by direct pulsations or quakes, or magnetically, that is, that the magnetic field was distrubed, as shown by the syphon or electric apparatus.

---

* See the "Bulletin," Vol. I, No. 2.

"The time at Midway would be in the neighborhood of Noon Thursday, Aug. 16 counting time westward; I am mentioning this as Midway is so close to the anti-prime meridian where the change of date takes place; for reckoning eastward it would be noon Aug. 17.

"There should have been noticed too on that day, after noon, one or more tidal waves coming from the west due to the quake. Perhaps the diary there will disclose that phenomenon.

"I would be very glad if your Supt. (Mr. Colley), at Midway would look up the syphon records for several hours about noon and see whether any disturbance is shown. Possibly he made a note on that day about the behaviour of the instruments.

"I would have written to him direct if I knew of any mail communication with Midway, hence I throw myself on your good nature.

"It is desirable that the time should be given as accurately as possible for any disturbance that may have been recorded or noted.

Yours sincerely,
OTTO KLOTZ."

"Commercial Pacific Cable Company.

Honolulu, H.T. July 16/07.

To Otto Klotz, Esq.,
My dear Mr. Klotz.

"Pardon the delay in answering your letter of April 12th—I have been very busy with outside work, which with the office work kept me fully occupied.

"I spoke to Mr. Colley over the wire and he looked over the slips, for several hours on each side of Noon, Aug. 16th and he says the instruments were in no way affected and no indications of tidal waves.

"I hardly expected, he would find any indications. We noticed none, during the San Francisco earthquake.

"We have felt one or two slight quakes, during the time I have lived here, but I could never discover any disturbance on the slip. A few nights ago we had a slight quake, it shook my bed, I thought of you, noted the time, and phoned the office, to mark the slips of both instruments, so I could examine them the next morning. I could not see the slightest disturbance--I was delighted you wrote me and shall always be glad to look up anything for you.

Very sincerely,
(Sgd) J. D. CAINES."

Earthquake of Sept. 3, 1907. The following account of the earthquake of Sept. 3. 1907, is taken from the Japan Times of Sept. 25, 1907.

"*Alarming sea-quake experience of the Kinsei.* The Japanese sealing schooner *Kinsei-maru* arrived at Hakodate on the morning of the 22nd of September from the Behring Sea, having taken 743 seal skins for the season.

"The master of the vessel reports all the other Japanese sealing vessels in the Behring Sea as doing well, and having between three and four hundred seals each.

"On the 20th of August, the *Kinsei-maru* during a gale slipped a sea which smashed all her boats and did other damage, thus compelling the vessel to start for home before the close of the season.

"On the 3rd of September, while the vessel was in 53 North and 170 degrees East, heavy, severe and continued submarine earthquake shocks were felt, and which lasted for over twenty-four hours, during which the vessel sailed 120 miles. One shock lasting for three minutes was so severe that it was thought that the vessel would go to pieces. The surface of the ocean was covered with dense masses of pumice stone for a distance of over two hundred miles."

Eureka earthquake of Aug. 18, 1908. The following letter from A.H. Bell, Esq., relates to the severe local shock felt at Eureka, in California, on Aug. 18, 1908.

"My Dear Sir: Eureka, California. August 18, 1908.

The heaviest earthquake experienced since the memorable 'shake-up' of April 18, 1906, occurred this morning at 2:59 o'clock. The vibrations lasted about fourteen seconds. Another shock of less severity was felt at 5:27 am., lasting about ten seconds. I am informed that this earthquake was not felt at San Francisco, the seismic motions extending about thirty miles north of Eureka and probably about the same distance to the southward. The damage done did not exceed $3000. I have just mailed detailed report to Prof. McAdie, San Francisco, California..........

Yours very truly,
Aaron H. Bell, U. S. Weather Bureau Office."

The following extract is taken from an Eureka daily paper:—

"....Weather Observer Aaron H. Bell stated this afternoon that the first and most severe quake this morning occurred exactly at 2:59 o'clock, and lasted about 14 seconds with vibrations from the southeast to the northwest. The violence was sufficient to stop clocks, rattle windows, and in the weather observer's office several instruments were disturbed. The greatest intensity was shortly after the beginning, gradually diminishing thereafter.

"The second earthquake this morning came at 5:27 o'clock, was of less violence and lasted about 10 seconds, the vibrations being upon the same direction as those of the first. Weather Observer Bell states that the quakes this morning were nothing as compared to the memorable one of two years ago in April, when San Francisco was almost wiped out of existence."

印刷所　三秀舍
東京市神田區美土代町二丁目一番地

印刷者　島連太郎
東京市神田區美土代町二丁目一番地

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Vol. II. No. 3.

December, 1908.
TOKYO.

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Note on the Long-period Variations of the Atmospheric Pressure.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XLIV—XLVIII.

1. ***Introduction.*** From the discussion of the after-shocks of the Mino-Owari and other recent destructive earthquakes in Japan,* the seismic frequency has been found to have, besides the diurnal and annual variations, the periodicities approximately of the lengths of 4½ days, 9 days, 12 days, 33 days, and 3 months; amongst others, the period of 4½ days occurring very often. The present note, which is to be regarded as a supplement to my paper on the secondary causes of earthquakes (the *Bulletin*, Vol. II, No. 2), gives some account of the longer periods of variation of the barometric pressure, the object being the comparison of the seismic and atmospheric periodicities.

2. ***1st method of finding out the periodicity of barometric pressure.*** The daily or other mean barometric pressure at a given place of observation is plotted on a section paper, and the length of a period is obtained by taking the average from the mean curve drawn by free hand extended over several consecutive months. (See Figs. 1, 2, and 3.) I give next some examples relating to Tokyo, Gifu, and Mt. Tsukuba.

---

* F. Omori: "On the after-shocks of earthquakes," Jour. Sc. Coll., Tokyo Imp. Univ., Vol. VII, (1894). Also F. Omori: "On the Earthquakes in Formosa," Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 54 (1905).

3. ***Barometric pressure at Tokyo, Gifu, and Mt. Tsukuba.*** As examples, I have taken the data relating to Tokyo, Gifu (province of Mino), and Mt. Tsukuba, and the average length of the different periods have been deduced from the curves, in which the ordinate is the mean barometric height corresponding to the time expressed in 1, 2, 5, or 10 days intervals. As may easily be imagined, the variation of the barometric pressure is generally very complex. In some cases, however, there is certain regularity, when the barometric variation indicates the periodicity of one kind or other. Thus, Fig. 1, which illustrates the variation of the daily mean pressure at Gifu between May 1 and Aug. 9, 1892, indicates a period of about 4½ days. Again, in Fig. 2, which represents the same variation in 1903 at the top observatory of Mt. Tsukuba, a period of 8 or 9 days is shown between Jan. 10 and Feb. 4, and in three other epochs, while a period of about 4½ days is shown during the rest of the year. Fig. 3 illustrates the 10-daily variation of the barometric pressure in Tokyo during the three years, 1887–1889, indicates more or less clearly a period of 3 months. The results obtained are summarized in the following table.

Time Interval.	The mean barometric pressure from whose variation the period has been deduced.	Average Length of Period.
	TOKYO.	
Oct. 1–Dec. 31, 1888.	Daily mean pressure.	4.7 days.
During the year 1888.	2-daily ,,	8.7 ,,
Jan. 1–Aug. 30, 1889.	2-daily ,,	32.0 ,,
During the 3 years, 1887–1889.	10-daily ,,	3 months.
	GIFU.	
Jan. 1–Sept. 9, 1892.	Daily mean pressure.	9.2 days ; 4.6 days.
Jan. 1–Aug. 31, 1893.	,, ,,	4.6 ,,
Sept. 1, 1891–March 31, 1892.	2-daily ,,	8.6 ,,
May 1–Dec. 31, 1892.	2-daily ,,	9.3 ,,
During the year 1893.	2-daily ,,	9.0 ,,
Do.	5-daily ,,	35.0 ,,
Do.	10-daily ,,	34.0 ,,
Sept. 1, 1891–Dec. 31, 1892.	10-daily ,,	3 months.
	MT. TSUKUBA.	
Nov. 18–Dec. 31, 1902.	Daily mean pressure.	8.6 days.
Jan. 10–Feb. 4, 1903.	,, ,,	8.3 ,,
Feb. 4–March 16, 1903.	,, ,,	4.4 ,,
March 19–April 13, 1903.	,, ,,	8.3 ,,
April 17–May 5, 1903.	,, ,,	4.5 ,,
May 5–May 31, 1903.	,, ,,	8.7 ,,
Oct. 17–Nov. 5, 1903.	,, ,,	5.0 ,,
Nov. 6–Dec. 23, 1903.	,, ,,	7.8 ,,

The different periods contained in the above table may be divided into 4 groups, i, ii, iii, and iv, as follows :—

i	ii	iii	iv
days	days	days	months.
4.7	8.7	32	3
4.6	9.2	35	
4.6	8.6		
4.4	9.3		
4.5	9.0		
5.0	8.6		
	8.3		
	8.3		
	8.7		
	7.8		
Mean..**4.6** days. ..	......**8.7** days	......33 days	......3 months.

The mean values of the 4 different periods are **4.6** days, **8.7** days, 33 days, and 3 months, the first two occurring most frequently.

4. ***2nd method of finding out the periodicity of barometric pressure.*** Instead of considering the variation of atmospheric pressure at a given place as explained in the preceding §, let us find out the time interval between the successive epochs, when the whole of Japan is covered by high barometric pressure. Thus, Figs. 4 and 5 represent two consecutive cases separated by about 4 days, when the high pressure area extended over the principal Japanese islands. The mean values of the different periods in the pressure variation obtained by this method from an examination of the weather maps of Japan during the 4 years, 1900 to 1903, are given in the following table.

Time Interval.		Number of times when high pressure area extended over Japan.	Average interval between the successive high pressure epochs.	
			day	hour
Jan. 3 ; 6 am.—May. 14 ; 10 pm.	1900.	29	5	2
Sept. 29 ; 10 pm.—Dec. 28 ; 10 pm.	„	21	4	12
Jan. 2 ;2 pm.— Feb. 9 ; 2 pm.	1901.	9	4	19
Feb. 18 ; 6 am.—March 21 ; 2 pm.	„	8	4	10
March 26 ; 10 pm.—June 1 ; 10 pm.	„	14	5	4
Sept. 29 ; 10 pm.—Dec. 27 ; 10 pm.	„	24	3	21
Dec. 31 ; 10 pm. 1901—April 6 ; 10 pm.	1902.	24	4	4
April 18 ; 6 am.—May 15 ; 2 pm.	„	8	3	22
May 25 ; 6 am.—July 1 ; 10 pm.	„	5	9	10
July 17 ; 6 am.—Aug. 27 ; 10 pm.	„	5	10	10
Oct. 5 ; 10 pm. 1902—Jan. 1 ; 2 pm.	1903.	23	4	0
Jan. 5 ; 2 pm.—Jan. 24 ; 6 am.	„	5	4	16
„ 28 ; 10 pm.—May 4 ; 6 am.	„	22	4	3
May 9 ; 10 pm.—June 21 ; 10 pm.	„	8	6	6

Taking the means from the above table, we obtain the following two periods :—

$$\begin{cases} \text{(i)} & 4^{\mathrm{d}}\;14^{\mathrm{h}} = 4.6^{\mathrm{days}} \quad \text{(averaged from 12 cases)} \\ \text{(ii)} & 9\;22 = 9.9 \quad (\;\text{„} \quad \text{„} \quad 2 \;\text{„}\;) \end{cases}$$

5. Combining the results obtained in §§ 3 and 4, the mean values of the first two periods are found to be :—

1st period .... **4.6** days.
2nd „ .... **9.3** „

Thus, the length of the 2nd period is double that of the 1st period, the latter being probably the fundamental period in the variation of the atmospheric pressure from day to day. It is quite possible that there exist, besides the period of 9.3 days and one of about 33 days, many others of longer or shorter durations, which are probably the multiples of the 1st period. The period of the length of 3 months may be of a different origin, being one of the harmonies of the annual period.

All the four periods in the variation of the barometric pressure as above obtained are evidently similar to, and likely to be the causes of, the corresponding periods in the variation of the earthquake frequency (§ 1).

I give next a short notice respecting the after-shocks of the Taito (Formosa) earthquake of 1903, whose frequency shows fluctuations parallel to those of the barometric pressure.

6. ***After-shocks of the Taito earthquake of Sept. 7, 1903.*** The following table gives the daily mean barometric pressure at Taito (Formosa) and the daily number of the after-shocks of the strong earthquake of Sept. 7, 1903, recorded at the same place by means of an Omori horizontal pendulum of 6 times magnification.

DAILY MEAN BAROMETRIC PRESSURE AND DAILY NUMBER OF EARTHQUAKES AT TAITO (FORMOSA). SEPT.—OCT., 1903.

Atmospheric Pressure.*			Daily Number of Earthquakes.		
Month / Day	September	October	Month / Day	September.	October.
	mm	mm			
1	760.0	754.6	1	———	0
2	58.8	56.5	2	———	0
3	58.6	57.8	3	———	0
4	59.2	53.6	4	———	0
5	59.6	53.2	5	———	0

* With freezing point correction. Reduction to standard gravity = 1.4mm; that to mean ea level = 0.9 mm.

Atmospheric Pressure.*			Daily Number of Earthquakes.		
Day \ Month	September.	October.	Day \ Month	September.	October.
	mm	mm			
6	58.8	58.4	6	———	0
7	57.8	58.2	7	26*	8
8	57.5	57.7	8	6	0
9	58.3	58.9	9	5	0
10	58.1	59.5	10	0	0
11	57.8	59.9	11	2	0
12	59.5	60.3	12	2	0
13	60.0	62.1	13	5	0
14	60.0	62.6	14	4	0
15	59.8	61.5	15	0	0
16	58.7	59.8	16	2	0
17	59.2	58.3	17	1	
18	60.4	57.7	18	5	
19	60.1	57.8	19	0	
20	59.0	57.9	20	0	
21	58.4	56.7	21	0	
22	58.9	55.6	22	0	
23	59.2	57.7	23	10	
24	60.4	59.6	24	4	
25	61.0	59.2	25	2	
26	59.0	58.3	26	2	
27	58.4	59.6	27	0	
28	58.2	62.6	28	1	
29	58.4	64.9	29	0	
30	56.8	64.1	30	0	
31	———	65.0	31	———	

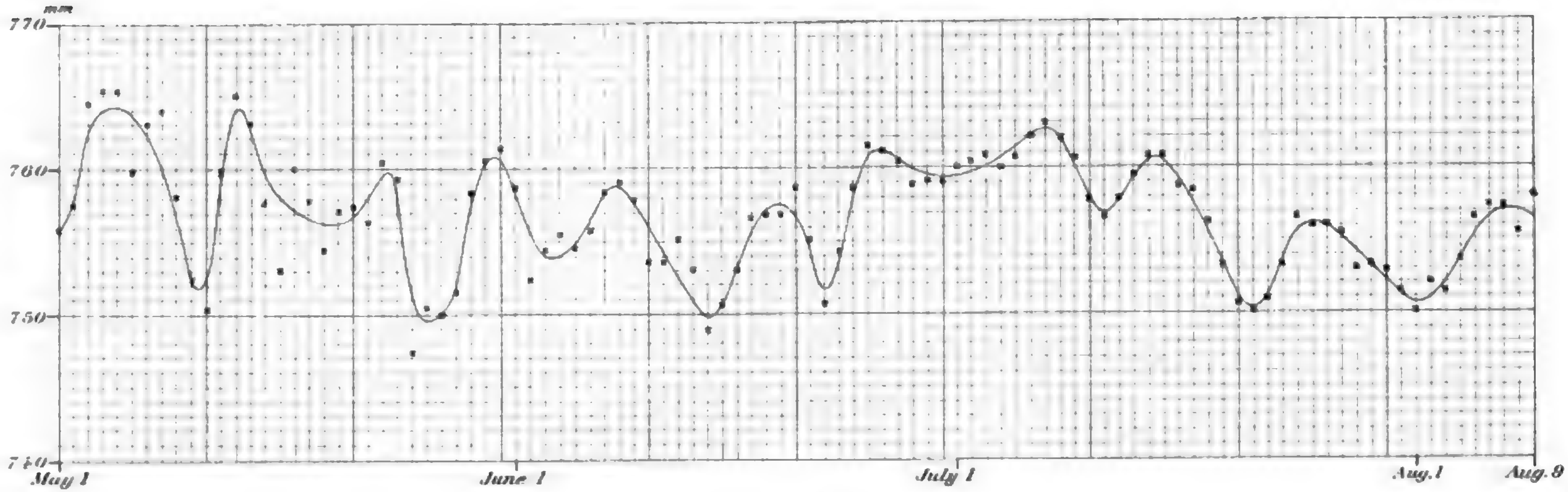
* The 1st shock took place at $2^{h}\ 59^{m}$ pm., on the 7th.

As will be seen from the graphical representations in Fig. 6, the variation of the barometric pressure between Sept. 8th and Oct. 8th (1903) indicates a period of the mean length of about 4.4 days, its maxima and minima corresponding, on the whole, respectively to the maxima and minima of the after-shock frequency.

Pl. XLIV.

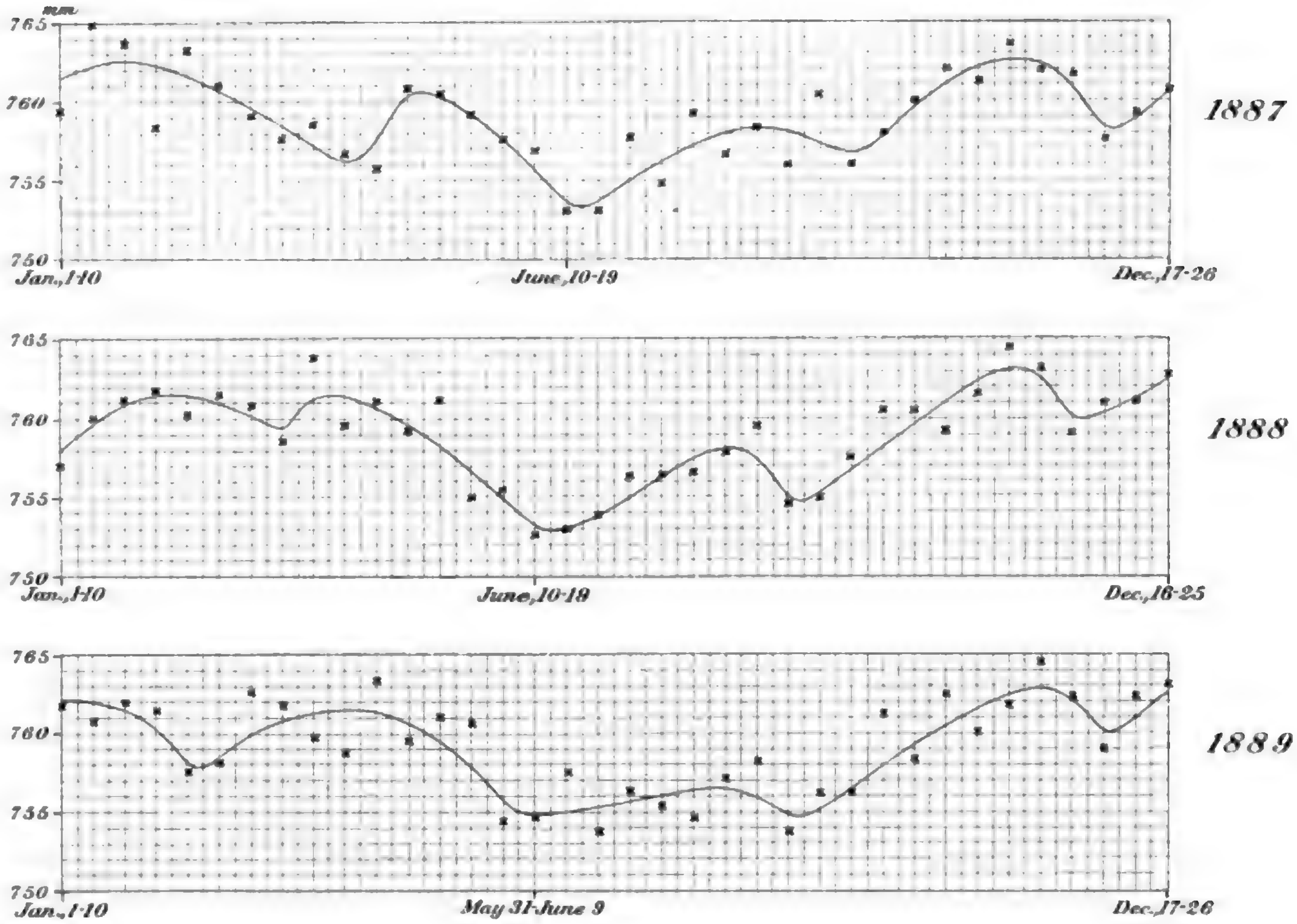
Fig. 1. Variation of Daily Mean Barometric Pressure at Gifu.

May 1 to Aug. 9, 1892.



(1892)

Fig. 3. Variation of 10-daily Mean Barometric Pressure in Tokyo.
1887, 1888, and 1889.



Maps showing the distribution of the Barometric Pressure over Japan.

Pl. XLVII.

Fig. 4. March 16, 1900; at 10 pm.

Fig. 5. March 20, 1900; at 10 pm.

Fig. 4.

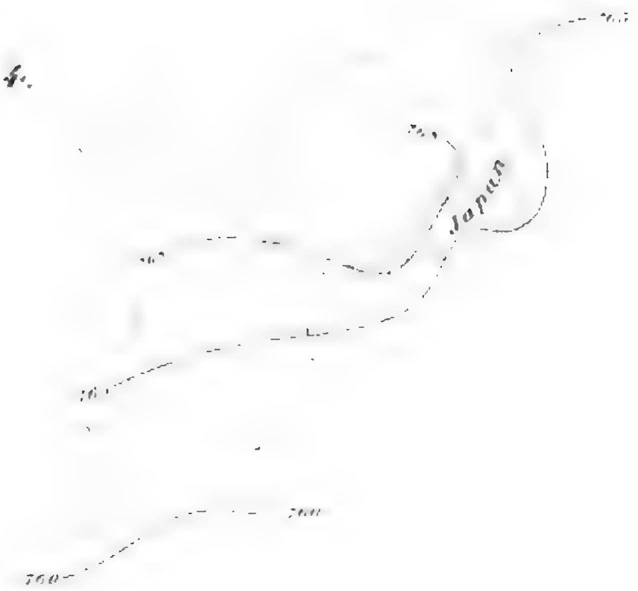
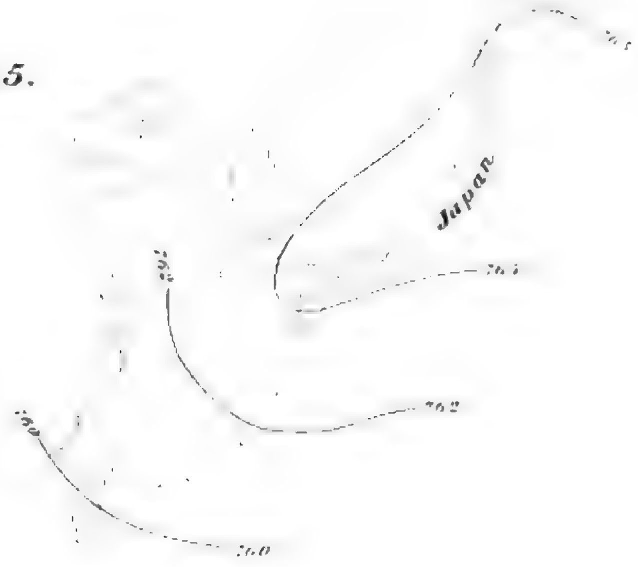

Japan
760
760

Fig. 5.


Japan
762
760

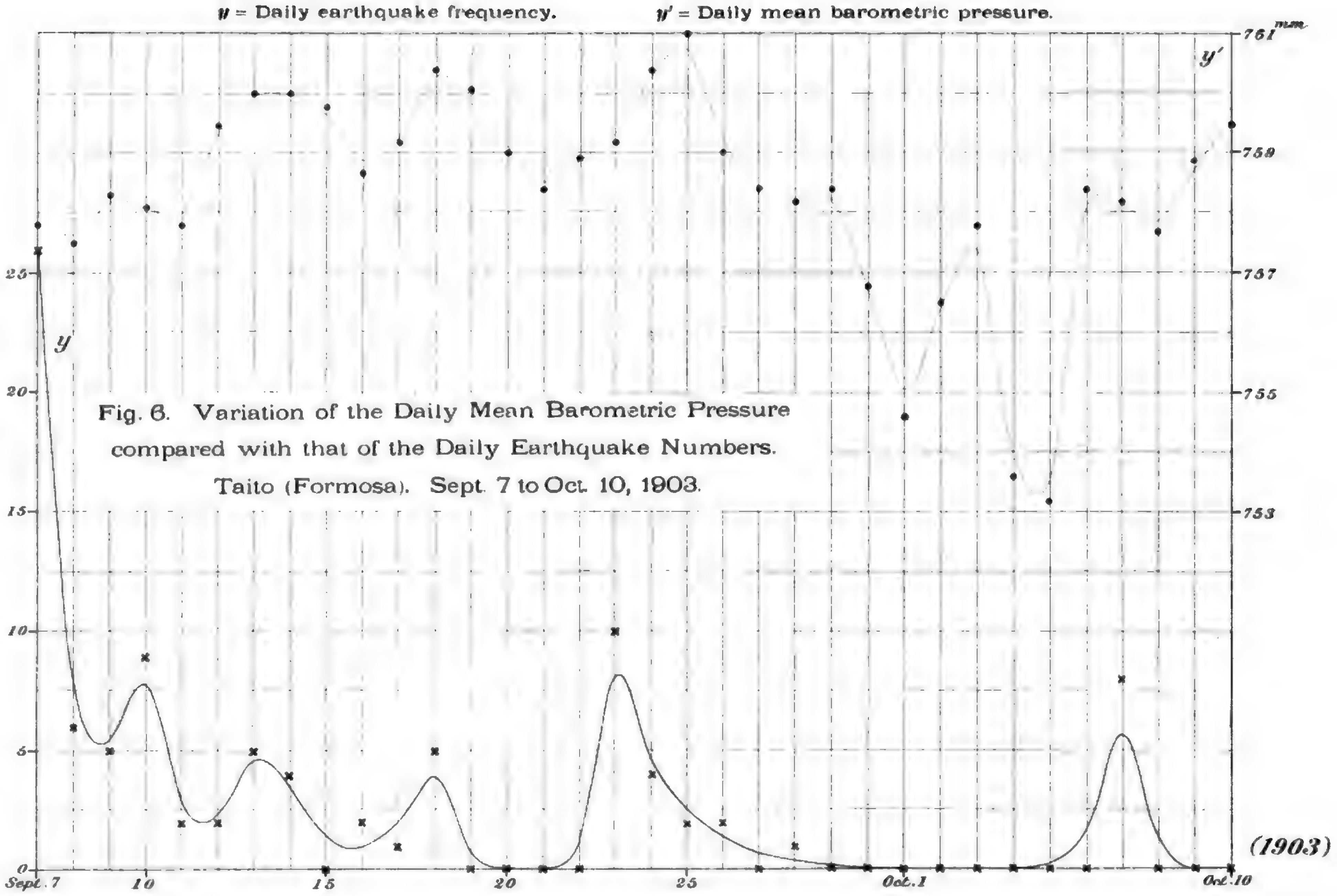


Fig. 6. Variation of the Daily Mean Barometric Pressure compared with that of the Daily Earthquake Numbers. Taito (Formosa). Sept. 7 to Oct. 10, 1903.

Experiments on the Vibration of Brick Columns.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XLIX-LII.

---

1. ***Columns.*** The present note gives an account of the experiments on the vibrations of five rectangular brick columns, whose dimensions were exactly alike, each being composed of 69 layers of 4 bricks. (See Fig. 1.) The height was 15 *shaku* (=495 cm), and the sectional area was 45.5×22.5 cm. The columns, composed of bricks of superior quality of one and the same kind (日本煉瓦會社製造燒過ギ), and fixed to a single large solid foundation of concrete specially made for the purpose, had mortars of different compositions, as follows:—

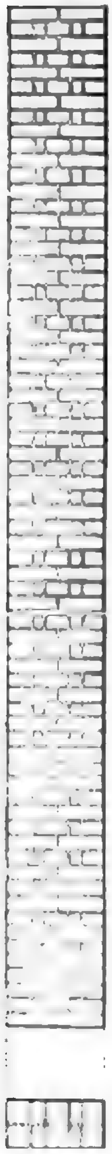
Column No. I...... Pure cement.
,, No. II .... 1 part of cement, 1 part of sand.
,, No. III.... 1 ,, , 2 ,,
,, No. IV .... 1 ,, , 3 ,,
,, No. V .... 4 parts of lime, 6 ,,

The columns, arranged in series as shown in Fig. 2, with a mutual distance of 50 cm were constructed between Nov. 25 and Dec. 18, in 1901.

2. ***Experiments.*** The object of the experiments carried on three months later, at the end of March 1902, was the determina-

tion of the periods of natural vibration of the different columns. For this purpose each of the latter was caused to move by being pushed or struck with hand once or several times at the top in direction normal to the broad side, being then left to vibrate freely and to gradually come to rest. The record of motion was obtained by means of a stiff pointer, which was attached to the top of the column, and to whose end was hinged a pen tracing in ink the vibrations on a record-receiver mounted on an independent staging of timbers. The diagrams obtained in this manner are reproduced in Plates XLIX to LII. The column No. V, of lime mortar, was very easily thrown into movements of a considerable amount; while the column No. I, of pure cement mortar, could be made to vibrate only slightly. Again, it happened almost always that, when one of the columns was vibrating, the neighbouring ones were also thrown into a state of motion to an appreciable degree. The following table gives for the different columns, the maximum or initial range (double amplitude $=2a$) of motion and the period of vibration during the earlier and end portions.

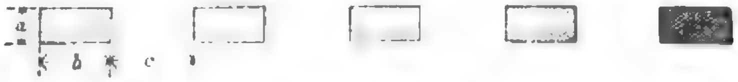
Fig. 1.



Brick Column. (Elevation and Section.)

Fig. 2.

Plan showing the arrangement of the columns in series.



$$\begin{cases} a = 22.5 \text{ cm.} \\ b = 45.5 \\ c = 50. \end{cases}$$

No. of Column.	No. of Experiment.	Initial or Max. $2a$.	Average Period in the	
			Earlier part.	End part.
		mm	sec.	sec.
I	1	0.8	——	0.23
	2	1.8	——	0.23
	3	4.3	0.24	0.24
	4	4.6	——	0.23
	5	7.0	0.25	0.25
	6	6.7	0.26	0.25
	7	6.3	0.26	0.25
	8	4.9	0.25	0.24
	9	8.0	0.27	0.24
	10	8.0	0.27	0.24
	11	6.9	0.26	0.25
	12	7.8	0.27	0.24
	13	5.9	0.27	0.25
	Mean.	**6.5** (1 and 2 excepted)	**0.26**	**0.24**
II	1	4.6	0.22	0·22
	2	4.7	0.24	0.23
	3	5.7	0.23	0.23
	4	5.3	——	——
	5	4.5	——	——
	6	6.7	0.24	0.23
	7	5.3	0.23	0.23
	Mean.	**5.3**	**0.23**	**0.23**
III	1	7.1	0.25	0.24
	2	6.8	0.25	0.23
	3	7.5	——	——
	4	9.5	0.27	0.24
	5	8.2	0.26	0.25
	Mean.	**7.8**	**0.26**	**0.24**

No. of Column.	No. of Experiment.	Initial or Max. $2a$.	Average Period in the	
			Earlier part.	End part.
		mm.	sec.	sec.
IV	1	5.5	0.24	0.24
	2	8.5 (Column broken)	0.31	0.25
	3	13.0	0.50	0.27
	4	16.5	0.54	0.25
	5	19.0	0.62	0.26
	Mean.	8.5—19.0	0.31—0.62	——
V	1	6.7	0.42	0.33
	2	9.4	0.45	0.35
	3	7.6	0.48	0.36
	4	17.1	0.62	0.37
	5	18.7	——	0.38
	6	21.5	0.67	0.41
	7	24.0	0.77	0.40
	8	3.9	——	0.40
	Mean.	3.9—24.0	0.42—0.77	0.33—0.41

The column No. I seemed to indicate a slight lengthening of period with the repetition of the vibration experiments. Thus, in the experiments Nos.3–8, the period in the earlier part of motion varied between 0.24 and 0.26 sec., with the average of 0.25 sec.; while in the experiments Nos.9–13, the corresponding period varied between 0.26 and 0.27 sec., with the average of 0.27 sec. The period in the later part of motion seems to show also a similar, though very slight, tendency.

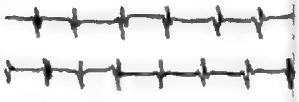
The same phenomenon is more markedly shown by the lime-mortar column No. V. Thus, during the eight experiments, Nos. 1–8, the period in the earlier part of motion successively increased from 0.42 up to 0.77 sec., while the period in the later part of motion increased from 0.33 up to 0.41 sec.

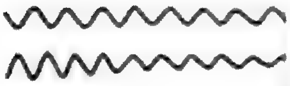
The lengthening of the vibration periods of the columns with the repetition of experiments is probably due to the formation of microscopically fine cracks at the joints and through bricks, which is equivalent to diminishing the elastic moduli of the columns without changing the mass.

3. ***Vibration of columns Nos. I-IV.*** From the above given table, it will be seen that the ranges (double amplitudes) of vibration of the different columns, although not caused by exactly one and the same amount of force, were nearly alike, the mean values varying between 5.3 and 8.5 mm. Half of the last-named limit of range of motion, which fractured the column No. IV, is to be taken as being the displacement at the top of the columns, which may break the latter at the base.

Again, the periods of vibration of the four columns under consideration were practically identical with one another, varying in the earlier, or large amplitude, part of motion only between 0.23 and 0.26 sec., and being in the later or end part between 0.23 and 0.24 sec. This uniformity of motion is quite contrary to what we should be led to expect; as the columns Nos. I, II, III, and IV, whose mortar composition varied from pure cement to 1 part of cement and 3 parts of sand, might be supposed to execute vibrations, of which both amplitude and period increase in proportion to the quantity of the sand mixed in the mortar. The apparent paradox can only be explained on the assumption that in each of the four columns, the mortar was much stronger than the bricks themselves and behaved as if it were practically incompressible, the result being that we got, in these experiments, only the vibrations due to the bricks, and not to the joints. It thus seems that in brick works a mortar of 1 part of cement and 1 to 3 parts of sand is as good as that of pure cement.

4. *Vibration of column No. V.* The column No. V of lime mortar, was thrown, without being broken, up to a vibration of 24 mm, which is nearly three times the maximum motion in the cases of the other columns. This was evidently on account of the inferior quality of the mortar, in consequence of which the elasticity of the bricks themselves did not, in the vibration of the column, at all come into play. Another remarkable feature in the motion of the column No. V was the great length of the vibration period, whose maximum value was 0.77 sec. The difference of the period of vibration for larger amplitude from that for smaller one ranged in the seven experiments, Nos.1–7, from 0.09 sec. to 0.37 sec. From experiments like these we can readily imagine how a tall brick chimney with bad mortar will be thrown, on the occasion of a violent earthquake, into slow oscillations of considerable amplitude.





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